

UNITED STATES ATOMIC ENERGY COMMISSION  
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**MASTER**

MINERALOGY AND PETROLOGY OF THE URANIUM DEPOSITS OF  
CANE SPRINGS CANYON, SAN JUAN AND GRAND COUNTIES, UTAH

By

Alice S. Corey

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May, 1959  
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# MINERALOGY AND PETROLOGY OF THE URANIUM DEPOSITS OF CANE SPRINGS CANYON, SAN JUAN AND GRAND COUNTIES, UTAH

## ABSTRACT

Uranium deposits in Cane Springs Canyon are on the northeast limb of the Cane Creek anticline. Ore occurs in the Moss Back member of the Chinle formation and the Moenkopi formation of Triassic age, and the Cutler and Rico formations of Permian age. The deposits on the east side of the canyon are chiefly confined to faults and joints while those on the west side are replacements of channel-fillings near fractures. The major ore mineral is uraninite which is invariably associated with organic matter. Secondary uranium minerals, including andersonite, carnotite, beta-zircons, and boltwoodite, are present at and near the surface. Vanadium and copper minerals are widespread, but not abundant.

As a result of local "dislocation metamorphism", biotite-quartz schist has formed in the fault zone in the Cutler formation.

The organic matter present in the area is pyrobitumen whose physical properties were determined by testing.

Color variations in ore zones and in country rock are due principally to presence or absence of hematite. Hematite is less-common in and near faults and fractures, whether or not they are ore-bearing.

## INTRODUCTION

### Location

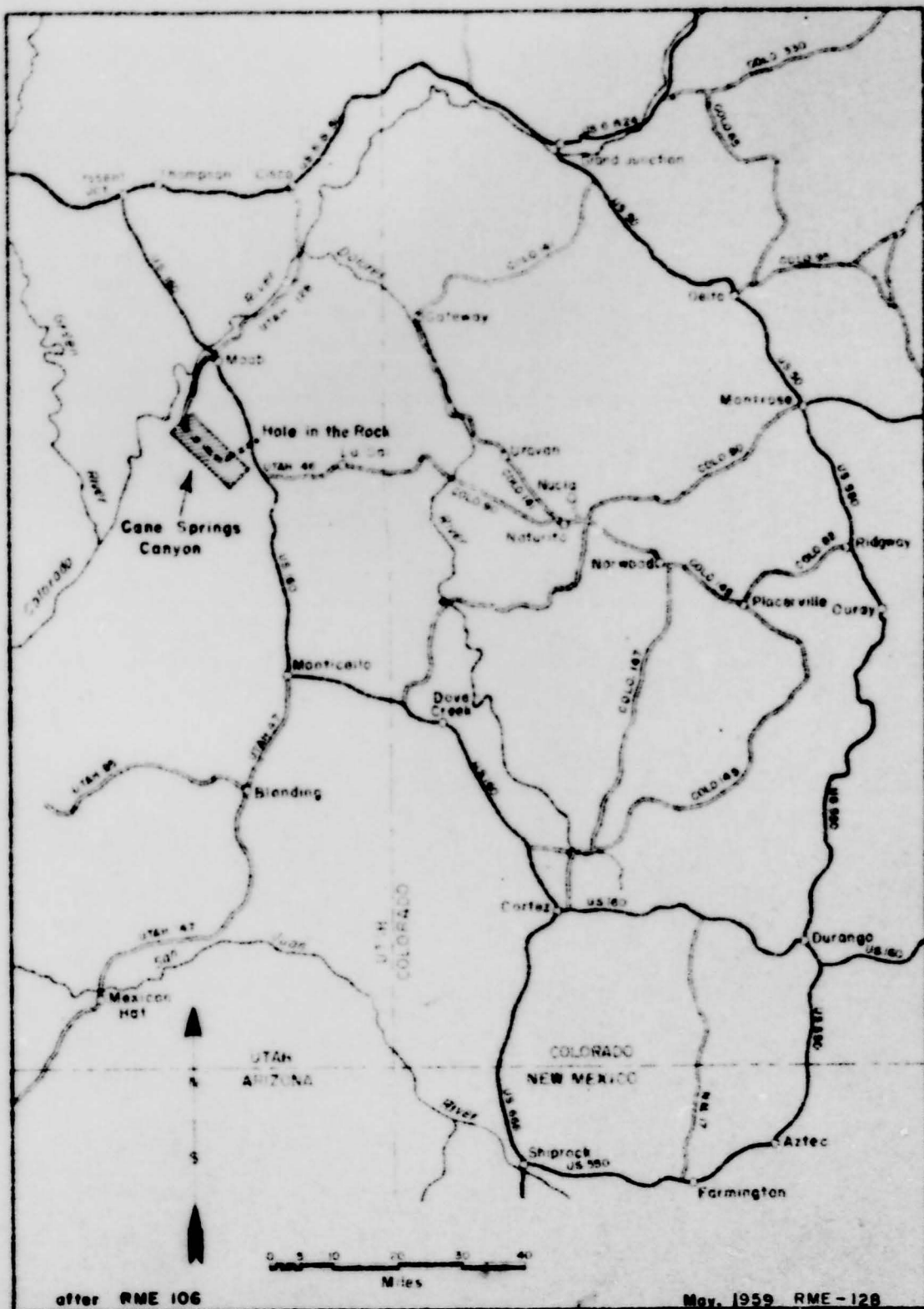
The uranium deposits of Cane Springs Canyon are in San Juan and Grand Counties, Utah, approximately 8 air miles southwest of Moab. Access to the area from Moab is gained via a gravelled road southward along the south side of the Colorado River and thence upstream along Cane Creek (fig. 1). Private roads lead to the various mines from the access road.

### Purpose

The study of the mineralogy and petrology of the uranium deposits of the area was originally undertaken to investigate the possible relations between the various color differences in the host rock and the uranium mineralization, and to study the differences, if any, between the "vein-type" deposits on the east side of the canyon and the "bedded" deposits on the west side. The study also included detailed mineralogic and petrographic investigations of the uranium ore and host rock and tests on uranium-bearing organic matter.

### Scope and methods

This study of the Cane Springs Canyon deposits was started in March, 1957. The mines studied are: Hercules, Honeybee, Honeybee No. 2, "B-prospect",



Canary, Moonshine, Red Zero, (fig. 2) and "Moss Back adit" on the east side of Cane Creek, and the Climax School Section mines on the west side. A total of 60 thin sections, 45 polished thin sections, and 90 polished sections of ore and country rock were examined in the laboratory. X-ray analyses of various minerals were made in the Denver laboratory of the U. S. Geological Survey by the writer. Spectrographic analyses were made by the U. S. Geological Survey staff in the Denver laboratory and by E. B. Gross in the U. S. Atomic Energy Commission Mineralogy Laboratory at Grand Junction, Colorado. Quantitative chemical analyses for ferrous and ferric iron content were made by Brown Laboratory, Grand Junction. The Grand Junction laboratory of Lucius Pitkin, Inc., made assays for  $U_3O_8$ ,  $eU_3O_8$ ,  $V_2O_5$ , and Cu.

#### GENERAL GEOLOGY AND STRUCTURE

Rocks exposed in Cane Springs Canyon (fig. 2) include the Rico and Cutler formations of the Permian age, the Moenkopi and Chinle formations and Wingate sandstone of Triassic age, and the Kayenta formation of Jurassic age. A stratigraphic section from McRae (1958) is shown in fig. 3. Uranium deposits are found in all formations from the Rico formation to the Moss Back member of the Chinle.

In the vicinity of the uranium deposits, Cane Springs Canyon intersects the Cane Creek anticline. This structure is a slightly asymmetrical fold about 15 miles long and 4 to 5 miles wide, trending N.  $50^{\circ}$  W. and plunging  $20^{\circ}$  NW. Baker (1933) believes that the anticline was first formed at the end of the Permian, with a second period of deformation after Moenkopi time and a third at the end of the Cretaceous, during which time "most of the structural features of the area are believed to have acquired their present form" (Baker p. 78). The flow of the salt in the Paradox formation was not the cause of the folding, but "after an anticline had started to form, regional pressure exerted on the plastic salt would tend to cause it to flow and accumulate under the areas which offered relief from the pressure -- namely, the upward-bowing anticlines; consequently the anticlines would have greater growth than pressure on nonplastic rocks would have caused" (Baker p. 76).

Several high-angle normal faults are present in the area. The Cane Creek fault (fig. 2) strikes N.  $40^{\circ}$  W., dips steeply northeast, and has been traced for approximately  $2\frac{1}{2}$  miles. In the SW  $\frac{1}{4}$  of sec. 13, T. 27 S., R. 21 E. it has a displacement of 40 feet (McRae, 1958). In sec. 3, T. 27 S., R. 21 E., north of the Honeybee mine, two other steeply dipping normal faults strike N.  $32^{\circ}$  W. and N.  $70^{\circ}$  W. (idem, 1958). Numerous other faults and joints occur in the vicinity.

All of the deposits in the area are on the northeast flank of the Cane Creek anticline (fig. 4). Most occur in or near the northeasterly dipping fractures of northwest-trending fault zones. The deposits, including the "bedded" deposits on the west side of the canyon, may be classified as vein deposits according to the definitions of veins given by Lindgren (1933), Emmons (1940) and others. The ore bodies on the east side of the canyon are chiefly confined to the faults and joints and are veins of the fissure type. Those on the west have replaced wall rock in channels near fractures.



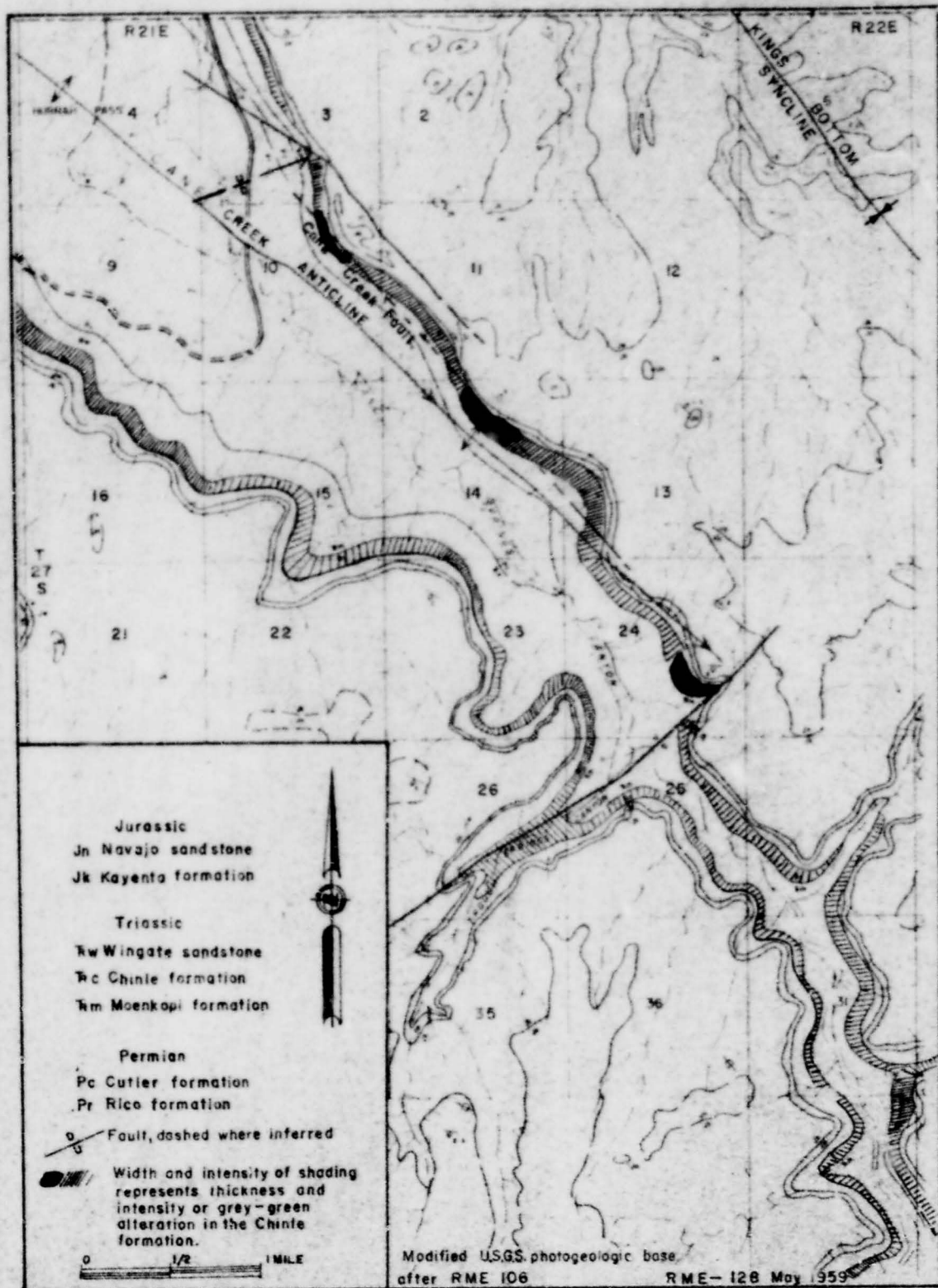


Figure 2. Relative thickness and intensity of grey-green coloration in the Chinle formation, Cane Springs Canyon, San Juan County, Utah



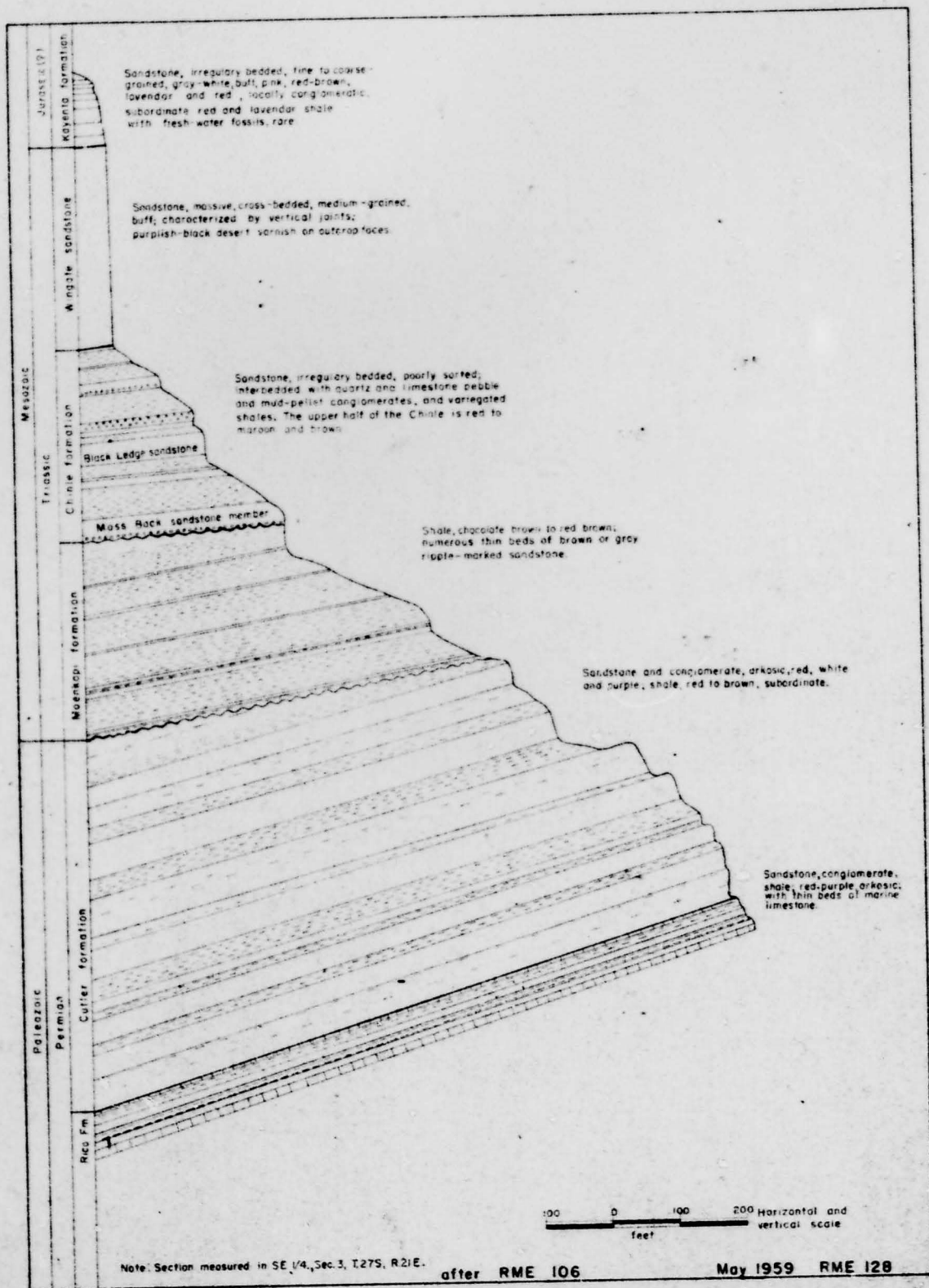


Figure 3. Columnar section, Cane Springs Canyon, San Juan County, Utah

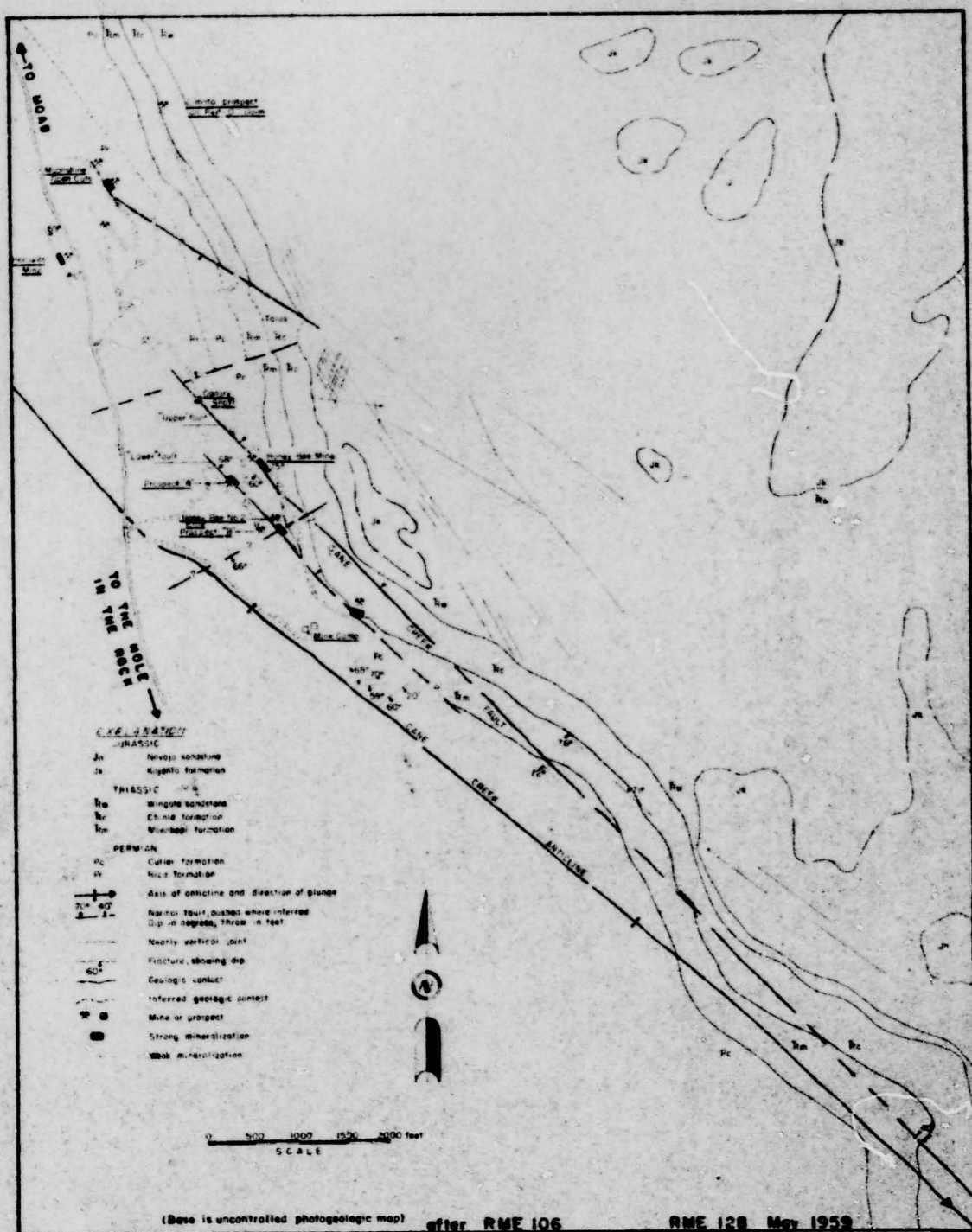


Figure 4. East side of Cane Springs Canyon, San Juan County, Utah

## MINERALOGY AND PETROLOGY

Uranium in the early ore shipments from each mine was present chiefly in secondary minerals. These minerals include andersonite,  $\text{Na}_2\text{Ca}(\text{UO}_2)(\text{CO}_3)_3 \cdot 6\text{H}_2\text{O}$ , beta-zippeite,  $(\text{UO}_2)_2(\text{SO}_4)(\text{OH})_2 \cdot 4\text{H}_2\text{O}$ , carnotite,  $\text{K}_2(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 1-3\text{H}_2\text{O}$ , boltwoodite,  $\text{K}_2(\text{UO}_2)_2(\text{SiO}_3)_2(\text{OH})_2 \cdot 5\text{H}_2\text{O}$  (Fron del and Ito, 1956), sharpite,  $(\text{UO}_2)(\text{CO}_3) \cdot \text{H}_2\text{O}$ , and masuyite,  $\text{UO}_3 \cdot 2\text{H}_2\text{O}$ . Mining at greater distances from the surface has resulted in the discovery of uraninite in most of the mines. In each instance the uraninite is in or near organic matter probably derived from plant remains which have since been metamorphosed to pyrobitumen. Vanadium minerals observed are montroseite,  $\text{VO}(\text{OH})$ , vanadium clay, and carnotite. Copper minerals include chalcopyrite, bornite, chalcocite, covellite, and malachite. Pyrite is ubiquitous, occurring in varying quantities in the deposits. Marcasite is less common.

The detailed mineralogy and petrology of the ore, host rock, and surrounding country rock will be discussed in ascending stratigraphic order for each mine.

### Hercules Mine

Uranium in the Hercules property (fig. 4) is in a northwest-trending fault zone in the Rico formation. Ore was removed from a shallow trench which parallels the fault. The Rico formation here is mainly arkose that contains a little mica, with calcite and hematite cement. The fault-filling consists of arkose, and of quartz-biotite schist formed by metamorphism of the arkose during faulting. The metamorphism is discussed below in the section on the Honeybee mine.

Secondary uranium mineralization in the Hercules formed disseminations and stringers of carnotite in the fault zone and for a few inches into the wall rock. No primary uranium mineral was found.

### Honeybee mine

Most of the ore mined on the east side of Cane Creek has come from the Honeybee mine (fig. 4) in the Cutler formation. The ore is in and near a northwest-trending, northeast-dipping fault zone.

Paul F. Kerr (oral communication 1957) reports that an age determination on Honeybee ore by J. L. Kulp resulted in a value of 50 to 60 million years.

### Lithology

The rocks of the Cutler formation examined in thin section consist mainly of poorly sorted arkosic sandstone cemented by calcite. The detrital grains consist of quartz, feldspar, varying amounts of mica, and accessory zircon, tourmaline, magnetite, chlorite, carbonaceous matter, and fragments of chert and granite. Grains vary in size from very fine to very coarse sand, but are mostly of medium size. The feldspar varies from fresh through all stages of alteration to sericite or kaolinite. Biotite and muscovite occur as large flakes or laths which are typically bent and twisted around more-resistant detrital minerals, although most of them lie with the longer dimensions parallel to the bedding planes.

The principal cement is calcite which varies from fine- to coarse-grained. In some zones the detrital grains have been corroded so that almost none are in contact. Here the interstices are filled with calcite, which is usually microcrystalline. It is not known whether the solutions that corroded the grains and those that deposited the calcite were the same. Calcite has replaced some of the detrital grains either partly or wholly (fig. 5).

Locally hematite is an important cementing and coloring material. The boundary between hematitic and non-hematitic rock is characteristically quite sharp. Hematite also forms a thin coating on some grains that are cemented mostly by calcite. Megascopically these rocks are generally of a lighter tint of red than the ones cemented by hematite alone. Where the grains have been corroded and replaced by calcite, the original boundaries may be marked by a thin band of hematite (fig. 5). Occasional veinlets of calcite cut across the calcite-cemented sandstone.

Within the mine minor amounts of clay-cemented sandstone, siltstone, and mudstone or shale were observed interlayered with the calcite-cemented arkose, but these rock types were not sampled at the surface because their outcrops are either covered or inaccessible.

The rock in the fault zone consists of calcite- and clay-cemented sandstone, minor siltstone and shale, and the metamorphic equivalents of these sedimentary rocks. During the process of faulting much of the argillaceous and feldspathic rock in the fault zone was altered. The amount of alteration is variable and the rock grades from unaltered sandstone, siltstone, and shale or mudstone to biotite-quartz schist (fig. 6).

Megascopically the non-uraniferous biotite-quartz schist varies from silvery green to dark green in color, and the uranium-bearing schist is dark gray to black. In thin section, the well-developed schist is seen to contain biotite, quartz, and varying amounts of muscovite and feldspar. The biotite is dark green to almost black in hand specimen. Microscopically it is pleochroic from dark green or brownish green to pale green, tan, or almost colorless. Mica crystals are as much as 1 millimeter in the longest dimension, but in the less well-developed portions of the schist they are much smaller. The quartz grains are only slightly fractured despite the evident faulting and metamorphism.

No quantitative determinations nor statistical studies were made of the feldspar content of the schist compared to that of the unmetamorphosed country rock because the sampling was not extensive enough for such studies. In the thin sections examined, however, the feldspar content of the quartz-biotite schist appears to be much less than that in the unmetamorphosed Cutler arkose. In addition, the percentage of detrital mica is much lower in the sections of faulted rock than in the country rock.

There are all gradations from biotite-quartz schist to unmetamorphosed country rock within relatively short distances. A single thin section may contain calcite- or clay-cemented sandstone at one end, and well-developed biotite-quartz schist at the other, with either a gradation or a sharp boundary between the two.



Portions of the faulted rock are rich in hematite and are colored various shades of red. Hematite is present in the unaltered sandstone, siltstone, and mudstone, and in all gradations of their metamorphic counterparts. At most places streaks of hematite in the fault parallel the strike and dip of the fault and also of the schistosity of the biotite-quartz schist.

### Metamorphism

The biotite-quartz schist is a pelitic schist belonging to the biotite-chlorite subfacies of the greenschist facies described by Turner (1948), Barth (1952), Ramberg (1952), and others. It corresponds to the biotite zone of Harker (1939). Rocks of the greenschist facies are metamorphic rocks of the lowest grade, recrystallized in the range of 100 to 250 degrees C. (Barth, 1952, p. 334) and moderate pressure (1000 to 1500 atmospheres) (ibid., fig. 137, p. 349). The greenschist facies, with its subfacies, is one of the normal products of regional metamorphism. These same products may also be derived by "local dislocation metamorphism" (Turner, 1948, p. 9) where the effects are "localized in proved dislocation zones".

No chlorite was observed in any of the sections from the Honeybee mine. The presence of biotite and absence of chlorite may indicate that metamorphism proceeded beyond the chlorite stage and converted any chlorite formed to biotite. On the other hand, chlorite may never have been present, probably because of lack of the proper constituents, mainly magnesium. Magnesium does not exceed 1 percent in the samples analyzed spectrographically (Table I).

One feature which points to the latter hypothesis is the presence of all gradations from well-developed biotite schist through biotite-bearing phyllite to shale, and clay-cemented sandstone, within very short distances. This indicates that the distribution of heat and pressure was irregular during faulting and that the mineral assemblage never reached equilibrium. Turner and Verhoogen (1951, p. 466) state that "owing to the extremely low velocity of chemical reaction between crystalline minerals throughout the lower range of metamorphic temperatures, chemical adjustment of a rock to such temperatures seldom proceeds beyond an incipient stage unless under the accelerating influence of synchronous deformation...and even where chemical reconstitution has been complete and deformation strong, disequilibrium is frequent in the mineral assemblage". According to Barth (1952), "the low temperature and, generally, the surface-near conditions have hindered the attainment of internal equilibrium". If the biotite-quartz schist were produced from the original sedimentary rocks via a chlorite schist intermediate stage, it seems likely that some chlorite would remain, especially in the intermediate zones between well-developed schist and unmetamorphosed sandstone and siltstone.

None of the biotite-quartz schist at Cane Creek shows laminated structure resulting from segregation of minerals into alternating layers paralleling the schistosity, a feature which is common in many schists. The mica is commonly somewhat twisted, which, according to Williams, Turner, and Gilbert (1954, p. 217), may indicate that "internal movements persisted to the close of metamorphism". No granulation nor undulatory extinction is observable in

Table 1

Semi-quantitative spectrographic analyses of selected samples from the fault zone in the Honeybee mine

Analyst: E. B. Gross

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Al	>10.	>10.	10.	>10.	>10.	5.	5.	5.	1.	.1
Ba	.005	.001	tr	.001	.001	tr	.01	.05	.01	.05
Ca	.1	.1	.1	.5	5.	.5	.5	.5	.5	.5
Cu	.005	.005	.005	.1	.05	.05	.1	.5	.1	.1
Fe	10.	10.	1.	1.	1.	5.	.5	.5	.5	1.
Mg	.1	.1	1.	.1	.05	1.	.5	.005	.005	.005
Mn	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.005	.001
Mo	0	0	0	0	0	0	0	0	0	0
Na	5.	5.	5.	5.	5.	1.	5.	<.1	.5	<.1
Pb	0	0	0	.01	.005	0	0	.01	.01	.1
Si	>10.	>10.	>10.	>10.	>10.	>10.	>10.	5.	5.	5.
Sr	0	0	0	0	0	0	0	0	0	0
Ti	.1	.5	.1	.05	.1	.1	.5	.005	.005	.005
U	0	0	0	0	.5	.5	1.	>10.	>10.	>10.
V	.5	.5	.5	5.	1.	.5	1.	.5	.5	.1

Figures are reported to the nearest number in the series 10, 5, 1, .5, .1, etc., in percent.

0 = Looked for, but not detected.

- (1) Rock types intermediate between sediments and biotite schist: some metamorphic mica and some clay.
- (2) Rock types intermediate between sediments and biotite schist.
- (3) Rock types intermediate between sediments and biotite schist.
- (4) Biotite schist and rock types intermediate between sediments and biotite schist.
- (5) Biotite schist and rock types intermediate between sediments and biotite schist.
- (6) Biotite schist (ore).
- (7) Biotite schist and rock types intermediate between sediments and biotite schist (ore).
- (8) Shale and rock types intermediate between sediments and biotite schist (ore).
- (9) Biotite schist (ore).
- (10) Biotite schist (ore).

the quartz. The grains are angular, but so are most of the detrital grains in the unmetamorphosed Cutler arkose. Because of its variability in the country rock, grain size does not help in determining whether the quartz has been granulated. Although feldspar is much less abundant in the well-developed schist than the average in the country rock, it is not completely absent. The small amount present is probably of detrital rather than metamorphic origin. No garnets nor amphiboles were observed, indicating that the degree of metamorphism remained low.

The biotite-quartz schist, then, is a product of low grade metamorphism produced on a small scale by local dislocation. The elements that were recrystallized into biotite were derived from the original constituents of the rock: potassium from orthoclase, microcline, mica, and hydromica; aluminum from clay and feldspar; silicon from feldspar, mica, clay, and quartz; iron from hematite; and oxygen from any of the minerals named.

Some calcite was crystallized later than the formation of the schist since it occurs in veinlets cutting across the schistosity. However, much of it probably crystallized during metamorphism. According to Barth (1952, p. 335), "if the carbon dioxide pressure is insufficient, neither calcite or dolomite will be able to grow. But field observations indicate that circulating carbonate-bearing solutions are almost always present in this type of rock (of the greenschist facies), that is, in lime-rich rocks almost always calcite (or dolomite) are able to form. To be sure, no lime-rich silicate close to the C-corner (of the ACF diagram) is stable in this facies. Thus no choice is left to a lime-rich rock; either calcite has to develop or the rock has to change its composition".

#### Organic material

During the period of faulting the organic material in and near the fault zone was altered and redistributed. The organic matter present today in the fault in the Honeybee mine has been metamorphosed beyond the stage where its origin can be definitely determined. Although there is some carbonaceous material present in the unaltered Cutler arkose, there is a much higher proportion in the fault zone. It seems likely that this was derived from sediments richer in organic debris than the Cutler, such as the Chinle, and was introduced into the fault zone and deposited, as open space fillings or by replacement, during or after the time of faulting but at some time preceding the introduction of uranium.

Much plant debris is plastic or liquid at some time during the decomposition cycle, even through the bituminous coal stage. Van Krevelen and Schuyer (1957, p. 275) report that small particles of bituminous coal flow plastically under pressure at room temperature. The same writers (p. 73) also state that "the hydrogen-rich maceral exinite...decomposes on heating into a very plastic "melt" which, for the greater part, is distilled over as tar". It is probable that the plant debris was not coalified to the bituminous stage at the time that it was subjected to the forces that redistributed and deposited some of it in the fault zones in the Cane Creek area. It is impossible to determine whether the present pyrobitumen was derived from matter which was emplaced as a result of plastic flow, liquid flow, or condensation from gaseous state. Whether the material deposited in the fault could have at any time been called petroleum is of little significance.

Physical tests on the pyrobitumen as it exists today are given in a later section. The organic matter was probably altered either continuously or intermittently during and after mineralization. The present pyrobitumen is black and varies in composition. Its hardness varies inversely as the degree of subdivision, and its luster varies from dull to bright. The pyrobitumen forms stringers, lenses, veinlets, and irregular elongate masses whose longest dimensions generally parallel the schistosity. Much of the pyrobitumen polishes well, but other portions of the pyrobitumen are sooty and do not polish and has variable, but generally low, reflectivity. Polished sections show low, non-uniform reflectivity and anisotropism in various shades of brown.

#### Post-fault primary minerals

Ankerite and calcite are the two earliest minerals to fill open spaces in the faults. The sections that contain brown ankerite are likely to contain calcite also. Both carbonates occur as cement and as veinlets, but interrelations between the two were not observed. Ankerite is most common in the vicinity of the carbonaceous material. Calcite was precipitated before, during, and after ore, but all of the ankerite observed appears to be pre-ore. Euhedral crystals of calcite were deposited as linings in open spaces later filled with chalcopryite (fig. 6).

Following deposition of ankerite, barite (fig. 7) was precipitated in the fault zone. Barite commonly occurs as radiating sheaves of blades replacing organic matter and ankerite, and filling open spaces. Spectrographic analyses (Table II) show a vague correlation of the percent of barium with that of uranium, probably a result of the relation of both with the fault rather than with each other.

The first ore element to be precipitated was vanadium which occurs in montroseite and vanadium clay. Montroseite is rare in the Honeybee mine but is found in irregular masses in and near carbonaceous matter. It has replaced mica in schist along cleavage planes (fig. 8). Direct age relations of montroseite with uraninite were not observed, but montroseite is veined by chalcopryite (fig. 8) which has overlapped the deposition of uraninite.

Vanadium clay corrodes and replaces nonvanadium clay and, in places, detrital quartz and feldspar. The vanadium clay is light to dark red-brown in thin section and has higher birefringence and coarser grain than the vanadium-free clay which is probably detrital. Vanadium probably entered the structure of the original clay during replacement and recrystallization.

In addition to veins in montroseite, chalcopryite occurs as scattered blebs and masses in the clay- and calcite-cemented sandstone and siltstone portions of the fault-filling, and in the adjacent biotite schist (fig. 8). It is finely disseminated in the pyrobitumen which contains uraninite (fig. 9), and in calcite veinlets which cut the uraniferous pyrobitumen. It veins the uraninite-organic intergrowth (fig. 10) and crackled uraninite masses. The most common occurrence is as replacement of barite (fig. 7), with growth originating along crystal faces and extending inward in all gradations through complete replacement so that in places pseudomorphs of chalcopryite after barite occur (fig. 11). Chalcopryite has also replaced



ankerite in irregular masses and has filled in around calcite crystals which were probably deposited in open spaces (fig. 6). It is probable that calcite preceded the chalcopryrite here because calcite has such a low force of crystallization that it would not be likely to grow crystal faces against pre-existing chalcopryrite.

Galena occurs principally as disseminated anhedral to subhedral crystals in chalcopryrite (fig. 11). No satisfactory explanation for this intergrowth has been found. Exsolution of galena from chalcopryrite seems unlikely, although not impossible. Galena also is found as disseminated blebs in pyrobitumen, in uraninite, and in calcite. Galena-bearing calcite veinlets cut uraninite-pyrobitumen intergrowths.

Pyrite is a minor constituent of the ores of the Honeybee mine. It occurs as small irregularly distributed anhedral masses cementing detrital grains, in calcite which cements grains and veins pyrobitumen, and as blebs in organic matter and schist. Rarely, it is found as replacement of chalcopryrite and barite.

The most abundant uranium mineral is uraninite which, most commonly, forms blebs and veinlets in organic matter (fig. 9). In many sections the uraninite-pyrobitumen intergrowth is so fine-grained that the two substances cannot be distinguished even under very high magnification. X-ray analyses of this submicroscopic intergrowth show the presence of uraninite. There are all gradations from nearly barren to highly uraniferous pyrobitumen.

Some uraninite veinlets are continuous from the pyrobitumen into the adjacent biotite-quartz schist (fig. 12) and uraninite is disseminated as patches in the schist, and cements sand grains in the unmetamorphosed sandstone. It is always close to organic matter.

Figures 7, 11, and 13 show uraninite that has replaced barite and chalcopryrite. Figure 14 illustrates the occurrence of uraninite as rounded blebs in ankerite and pyrobitumen. The shape of the uraninite grains may be due to deposition in the colloidal state. In sandy portions uraninite has replaced detrital mica along cleavage planes and has replaced quartz in an irregular pattern (fig. 10).

In one section chalcocite occurs as small anhedral crystals in chalcopryrite.

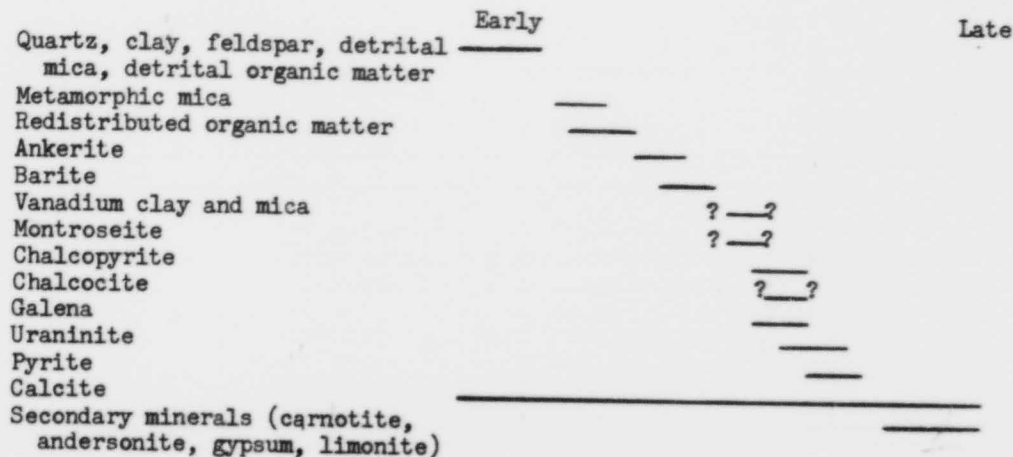
#### Oxidized minerals

The only uranium minerals found at the outcrop are secondary andersonite and carnotite. With increasing depth from the surface the amount of oxidation decreases and uraninite becomes the predominant uranium mineral.

Oxidized minerals other than those of uranium include gypsum and "limonite" which are common throughout the mine.

## Paragenesis

The following paragenetic sequence is proposed for the ore in the Honeybee mine:



### Honeybee No. 2 mine

The Honeybee No. 2 mine (fig. 4) is near the top of the Cutler formation in sec. 10, T. 27 S., R. 21 E. Mining has been confined to a fault zone trending northwest and dipping steeply northeast. The fault zone is up to 12 feet wide in the area mined (fig. 15).

### Lithology

The unfaulted country rock in the vicinity of the mine consists mainly of fine- to medium-grained, poorly sorted sandstone, mostly red in color, but white in occasional thin layers and scattered irregular patches. Some thin layers of shale are interbedded with the sandstone. Principal detrital constituents are angular to subangular grains of quartz, with feldspar and varying amounts of mica. Accessories include zircon, tourmaline, magnetite, chert fragments, and fine-grained carbonaceous matter.

The cement is mainly calcite, although in some layers and in local patches clay, fine-grained mica, hematite, and rock flour are more abundant. Hematite constitutes as much as about 2 percent of the red rock whereas the light-gray and white portions contain practically none. Most of the contacts between the hematitic and non-hematitic portions are sharp. Irregular, discontinuous patches of authigenic quartz cement up to a few millimeters in diameter were observed in thin section.

Except for the presence of ore-minerals, the rock in the fault zone differs very little from the surrounding country rock. Much arkose is interbedded with a little siltstone and mudstone. One thin bed of limestone that contains rare quartz fragments was observed.

### Organic material

The concentration of organic matter appears to be greater in the mine than in the country rock outside of it. This may be due to the fact that the carbonaceous matter is very friable, eroding more easily than other rock constituents, and therefore does not crop out. On the other hand, the organic material may have been introduced into the fault during or after the time of faulting. The carbonaceous matter parallels original bedding planes rather than fault planes and is more common in the finer sediments. It occurs in angular discrete fragments resembling desiccated coal. Physical tests performed on the organic material show that it is now a pyrobitumen. Generally the pyrobitumen did not lend itself to polishing, but occasional fragments that did polish show low reflectivity with anisotropism in shades of brown.

Unlike the pyrobitumens from the other mines in the Cane Creek area, that from the Honeybee No. 2 mine is only slightly radioactive. Moreover, chemical and radiometric assays (Table 2) show that the material is strongly out of equilibrium, with much higher  $eU_3O_8$  than chemical  $U_3O_8$ .

### Post-fault mineralization and alteration

Traces of uraninite and chalcopyrite were found in one section of pyrobitumen. However, most of the uranium in the Honeybee No. 2 mine is present in secondary minerals, mainly boltwoodite and andersonite. Whether these were derived by oxidation of primary uraninite in the mine area or whether the oxidized uranium was carried in from outside the immediate vicinity is not known.

Other products of oxidation in the mine include limonite and stringers and veinlets of gypsum.

Except for local irregular patches little hematite is present in the vicinity of the fault where mining has taken place. At the inner end of the mine tunnel, a good example of bleaching along fractures has been uncovered. Here, the hematite-bearing rock has been fractured in several directions with spacings between fractures of from 5 to 10 inches. For about 2 to 4 inches on either side of each fracture the rock is almost white, with only remnants of red persisting farther away from the fractures (fig. 16). Although in many places along Cane Creek it is not known whether the present distribution of hematite is due to original deposition patterns or to later removal of iron in certain zones, it seems safe to assume that in the Honeybee No. 2 mine the white zones are due to removal of hematite.

### "B" prospect

A short tunnel, called the "B" Prospect (fig. 4), located in sec. 10, T. 27 S., R. 21 E., just below the Honeybee No. 2 mine, intersects the fault in which the Honeybee No. 2 mine occurs. The faulted rock contains mostly unaltered arkose and minor amounts of altered foliated rock. Foliation parallels the fault and was probably produced by faulting. No uranium minerals were observed in the mine or in the sections prepared from samples collected from it. Radioactivity in the tunnel is essentially the same as the background for the area.

Table 2

Sample	<u>Assays</u>							U/Cu
	%U <sub>3</sub> O <sub>8</sub>	%U <sub>3</sub> O <sub>8</sub>	%V <sub>2</sub> O <sub>5</sub>	%Cu	%U	%V	U/V	
1	17.23	15.28	1.74	0.01	14.20	0.975	14.6	10 <sup>3</sup>
2	1.41	1.18	0.91	0.06	1.16	0.51	2.3	2 x 10
3	1.17	1.17	0.24	0.02	0.96	0.13	7.4	5 x 10
4	11.70	11.07	1.16	0.71	9.64	0.650	14.8	14
5	0.01	0.31	0.20	Nil	0.008	0.11	0.07	--
6	0.28	0.44	0.38	0.02	0.23	0.21	1.1	10
7	0.02	0.23	--	--	0.016	--	--	--
8	14.33	15.15	6.73	--	11.81	3.77	3.13	--
9	5.77	5.71	0.06	Nil	4.76	0.03	2 x 10 <sup>2</sup>	--
10	56.35	32.38	0.43	Nil	46.45	0.24	19 x 10 <sup>2</sup>	
11	29.38	25.08	0.54	0.01	24.22	0.30	81	2 x 10 <sup>3</sup>
12	1.59	2.19	1.33	0.44	1.31	0.745	1.76	3.0
13	1.83	2.10	1.46	0.14	1.50	0.818	1.83	1.1
14	14.91	13.74	8.42	0.40	12.29	4.72	2.60	31
15	31.91	27.37	3.02	0.07	26.30	1.69	15.6	4 x 10 <sup>2</sup>
16	20.28	18.93	1.18	0.03	16.72	0.661	25.3	6 x 10 <sup>2</sup>

-- not determined

- (1) Honeybee mine, ore in fault
- (2) Honeybee mine, ore in fault
- (3) Honeybee mine, ore in fault
- (4) Honeybee mine, ore in fault
- (5) Honeybee No. 2 mine, carbonaceous material in fault
- (6) Honeybee No. 2 mine, oxidized uranium ore at outcrop
- (7) Honeybee No. 2 mine, carbonaceous material in fault
- (8) Honeybee No. 2 mine, carbonaceous material and oxidized uranium ore in fault
- (9) Moss Back adit, oxidized ore in fossil log at outcrop
- (10) Moss Back adit, pyrobitumen surrounding fossil log in adit
- (11) Moss Back adit, partly oxidized uraninite-bearing log
- (12) Canary claim, andersonite ore in sandstone, in fault
- (13) Canary claim, andersonite ore in sandstone, in fault
- (14) Adair mine, sandstone ore
- (15) Climax School Section mine, ore from channel
- (16) Climax School Section mine, ore from channel

### Canary shaft

Mine workings on the Canary claim (fig. 4) consists of a pit approximately 20 feet deep in the same fault system as that of the Honeybee mine. The Canary pit is in the Cutler formation on the north limb of the Cane Creek anticline, northwest of the Honeybee mine. The rock is an arkose that contains up to 10 percent mica and is cemented by clay and medium- to coarse-grained calcite.

No primary uranium mineral was observed, but it is quite probable that deeper mining will expose primary uranium minerals. "Uranium minerals are mainly andersonite which forms veinlets and coatings." Some of the clay cement is vanadium-bearing.

A yellow uranium carbonate tentatively identified as sharpite,  $(\text{UO}_2)_6(\text{CO}_3)_5(\text{OH})_2 \cdot 7\text{H}_2\text{O} (?)$ , was found in one small sample. This mineral fluoresces yellow under ultraviolet light. It occurs as very fine blades which have parallel extinction, high birefringence, and pleochroism from pale yellow to almost colorless. No interference figures could be obtained because of the small size of the crystals. The indices determined are:  $\gamma (?) = 1.72$  and  $\alpha (?) = 1.63$ . These values are in good agreement with those given for sharpite by Palache, Berman, and Frondel (1951, p. 275), who give the following optical properties for sharpite from Chinkolobwe, Belgian Congo:

Orientation	n	pleochroism
X	1.633	brownish
Y	1 laths	biaxial (f)
Z	elong. ~ 1.72	yellowish green

According to Frondel, Riska, and Frondel (1956), authentic X-ray data on sharpite are lacking. The following d-spacings were measured for the Cane Creek material:

<sup>0</sup> d (Å)	Intensity	
8.1	VS	
7.5	W	
7.0	M	VS very strong, S strong,
4.05	S	M medium, W weak
3.71	M	
3.50	W	
3.12	W	
2.85	W	

### Moonshine claim

No radioactivity was detected and no uranium minerals observed on the Moonshine claim (fig. 4). Several prospect pits have been dug along a minor northwest-trending, northeast-dipping fault in the Cutler arkose. Thin coatings of malachite occur on fracture surfaces.

### Red Zero claim

A small amount of uranium was found in the Red Zero claim (fig. 4) in the Moenkopi formation. Host rocks are limy, mudstone-pellet conglomerate and sandstone, and argillaceous limestone containing scattered mudstone pellets. The ore is in a faulted area and was observed only in irregular pockets a few feet across, although several exploratory drifts have been excavated. Uranium is present mostly as carnotite which coats detrital grains, particularly mudstone pellets. More rarely, it occurs as uraninite in small carbonaceous pellets and coalified wood fragments. Gypsum and limonite are abundant as coatings on fissure walls and in fossil wood.

### "Moss Back adit"

On the east side of the canyon uranium minerals occur in the Moss Back member of the Chinle formation as replacement of organic matter, mainly in large logs which have been coalified. The logs are in the sandstone near the extension of the fault found at the Honeybee mine. Most of the faulted rock had been eroded from the area in which the uranium occurs in the Moss Back. High grade coalified logs have been selectively mined at the outcrop. A short adit, called the "Moss Back adit", has also been driven. Here, other mineralized logs were uncovered.

### Lithology

In the vicinity of the mineralized logs the country rock consists of interbedded calcite-cemented sandstone, calcareous siltstone, and both pure and argillaceous limestone. The detrital grains in the sandstone are mainly quartz with minor feldspar and accessory mica, zircon, chalcedony, and magnetite. In a few layers, however, many or most of the grains are limestone.

Late calcite veinlets up to 1.5 mm. thick cut the rock in places, and calcite scalenohedrons up to an inch wide, many intergrown with celestite blades up to an inch or more in length, have formed in fissures and other open spaces. Celestite cements detrital grains. Megascopically the calcite is white to pink and the celestite is mottled white, pink to peach, or pale yellow-green.

### Organic material

Much of the cellular texture of the coalified wood has been retained where it has been replaced by mineral constituents (fig. 17), but no cell structure was observed in unmineralized coalified wood.

A 1-inch layer of non-cellular uraniferous organic material was found adjacent to one of the logs in the adit. This pyrobitumen is probably derived from the fossil wood during some phase of alteration prior to uranium mineralization. Some of the physical properties of this pyrobitumen are given in Table 3. After mineralization there was additional redistribution of organic material into shrinkage cracks in uraninite (fig. 18).

In addition to the mineralized carbonaceous matter, many small non-mineralized fragments are scattered through the rock in the vicinity of the



Moss Back adit. In polished section most of the organic material, whether uraniferous or non-uraniferous, is anisotropic in varying degrees, with interference colors in shades of brown.

#### Uranium and associated minerals

Uraninite has replaced various portions of the fossil wood and other pyrobitumen. At different places within a single log it has replaced cell centers (fig. 19) and cell walls (fig. 17). The cell texture may be clearly defined or distorted and nearly or completely destroyed. In the pyrobitumen at the margin of the log in the adit, uraninite occurs as tiny disseminated blebs.

Pyrite also has preserved the cell structure of wood while replacing it in varying degrees (fig. 20). In places it has replaced all parts of the fossil wood except for an outline of the cells consisting of carbonaceous matter or calcite. Elsewhere it has replaced only the lumens or only the cell walls. Other occurrences of pyrite include cubes and irregular masses in uraninite. Blebs of pyrite occur in late calcite veinlets in the organic matter outside the fossil log. Veinlets of solid pyrite cut earlier pyrite which has replaced cells. Stringers of cubes and blebs of pyrite alternate with calcite along scalenohedral faces (fig. 21). Pyrite has formed arborescent skeletal crystals in calcite (fig. 22). In a peculiar orbicular intergrowth of pyrite with calcite (fig. 23), the orbs seem much too large to have been formed by replacement of individual wood cells. Rarely pyrite cements sandstone outside the logs.

Marcasite has precipitated alternately with calcite in the same manner as pyrite (fig. 24), but the crystals are needles rather than cubes. Marcasite also occurs as rounded or irregularly shaped masses in calcite.

Minor amounts of chalcopyrite occur as cement in sandstone.

Calcite has replaced most of the organic matter of fossil wood not replaced by metallic minerals. Some calcite was precipitated alternately with pyrite and marcasite. Calcite veins massive pyrite and marcasite and has replaced pyrite cubes. Where uraninite occupies cell walls, calcite has filled the lumens (fig. 17); conversely where uraninite occupies the lumens, calcite has replaced cell walls (fig. 19). Calcite veins massive uraninite and uraninite-organic intergrowths.

#### Oxidation

The mineralized logs have been altered by recent weathering so that the uraninite has been oxidized and secondary uranium minerals have formed as veinlets and coatings in and near the fossil logs. The secondary uranium minerals include beta-zippeite, andersonite, boltwoodite, and rarely, an orange-yellow mineral tentatively identified as masuyite,  $\text{UO}_3 \cdot 2\text{H}_2\text{O}$ .

Optical properties of this masuyite, as compared to data given for masuyite by Frondel (1956, p. 563), are:

Masuyite (Frondel)	Cane Creek mineral (Corey)
$\alpha$ 1.785 pale yellow	1.765 colorless
$\beta$ 1.906 deep golden	1.882 yellow
$\gamma$ 1.917 deep golden	1.887 yellow
Orthorhombic, (-)	Biaxial (-)
2V = 50°	2V = 0 - 10°
X perpendicular to cleavage	X perpendicular to cleavage

The d-spacings for masuyite from Katanga, Belgian Congo, Frondel, Riska, and Frondel (1956) and for that from Cane Creek are:

Katanga		Cane Creek	
d-spacings (Å)	Intensity	d-spacings (Å)	Intensity
8.53	1	7.2	VS
7.10	10	6.8	W
		6.6	W
6.43	2	6.3	W
		5.7	VW
4.80	1		
4.35	4	4.4	VW
3.92	2		
3.54	8	3.58	S
		3.53	S
3.15	9	3.17	S
2.97	1	2.94	W
2.74	3	2.80	W
2.51	5	2.51	M
2.38	2	2.38	W
2.06	1	2.08	W
1.984	6	1.97	M

Frondel (1956, p. 554) states that "the X-ray pattern of masuyite is virtually identical with that of vandendriesscheite", ( $\text{PbO} \cdot 7\text{UO}_3 \cdot 12\text{H}_2\text{O}(?)$ ). Since no lead was detected in the Cane Creek material and since the optical properties are very near to those given for masuyite, the mineral is tentatively called masuyite. However, Frondel, Riska, and Frondel (1956, p. 113) state: "There is also a more or less close resemblance in pattern [of fourmarierite,  $\text{PbO} \cdot 4\text{UO}_3 \cdot 7\text{H}_2\text{O}(?)$ ] to vandendriesscheite, masuyite, and schoepite ( $2\text{UO}_3 \cdot 5\text{H}_2\text{O}$ ), and these minerals are at least closely related in structure -- if indeed, a continuous series does not extend between them. The patterns of all of these minerals are distinguished by a pair of very dark lines with  $d = 3.4$ - $3.6$  and  $d = 3.0$  -  $3.2$ ". The pattern of the Cane Creek mineral shows 2 strong lines in the  $3.4$  -  $3.6$  range and may be of some intermediate composition, possibly containing slightly more water than masuyite.

Much of the pyrite has been oxidized, with subsequent formation of hematite, limonite, and gypsum. Hematite with metallic luster has formed pseudomorphs after pyrite. Whereas powdery red hematite occurs disseminated



throughout the logs and surrounding rocks. Gypsum veinlets occur in mineralized logs and in the sandstone.

Kaolinite stringers and veinlets up to 0.5 inch across, probably derived from alteration of feldspar, are found in the sandstone surrounding the mineralized fossil wood.

### Paragenesis

The following paragenesis is suggested:

	Early	Late
Detrital minerals	_____	
Calcite	_____	
Celestite	_____	
Uraninite	_____	
Pyrite	_____	
Marcasite	_____	
Redistributed organic matter	_____	
Oxidation products (hematite, etc.)		_____

### Adair mine

Uranium ore in the Adair mine, sec. 32, T. 26 S., R. 21 E., Grand County, occurs in the Moss Back member of the Chinle formation. The ore which is in sandy carbonaceous lenses in a shallow channel, was mined by stoping on either side of a 150-foot, northwest-trending adit.

### Lithology

The host rock is calcite-cemented sandstone, generally medium-grained, which, on either side of the ore grades into calcareous siltstone interbedded with limestone, shale, and minor sandy layers. The sandstone contains a large percentage of argillaceous limestone pebbles (fig. 25) and is locally conglomeratic, containing limestone pebbles up to 15 millimeters in diameter (fig. 26). Other detritals are quartz, feldspar, mica, chert fragments, fossil wood, and accessory zircon, magnetite, and tourmaline. In some silty layers mica is a major constituent, producing fissility parallel to the bedding planes.

In the vicinity of the ore calcite is the main nonmetallic cementing agent. Farther from the ore hematite is locally abundant in the siltstone layers, imparting a bright rusty color to the rock. Hematite was not observed in or near the ore.

### Organic material

Altered woody matter is common throughout the mine. In places the organic material has been entirely replaced by various minerals (fig. 27) and in others the wood has been coalified and only partly mineralized (fig. 28). Optically the pyrobitumen is anisotropic with brown interference colors. Some of the physical properties of the pyrobitumen are discussed in a following section. In addition to the residual carbonaceous matter remaining

in its original position, small amounts of liquid or plastic organic matter flowed into cracks in the coalified wood at some time after introduction of uranium.

#### Uranium and associated minerals

Uranium is present mainly as uraninite which has commonly replaced the cell walls of fossil wood (fig. 27) with calcite occupying the lumens. Occasionally only a ring of uraninite remains with calcite occupying the inner layers of the cell walls as well as the lumens (fig. 29). Elsewhere uraninite has replaced all parts of the wood indiscriminately. Possibly the cell texture was destroyed before the introduction of the metallic minerals. Uraninite cements detrital grains (fig. 30) and has replaced parts of grains of impure limestone (figs. 26, 30).

Vanadium minerals present are vanadium clay and montroseite. The fine-grained brown vanadium clay cements sand grains near carbonaceous matter, and montroseite occurs as needles and fibrous intergrowths that cement sand grains at the margins of fossil wood fragments. In polished section the intergrowths of acicular crystals appear massive in ordinary light, but under crossed nicols the anisotropism of the montroseite needles shows the structure clearly. Montroseite has replaced mica along cleavage planes (fig. 21) but otherwise commonly occurs in interstices (fig. 26).

Pyrite is more abundant in fossil wood which has not been entirely mineralized than in the completely mineralized wood. In the coalified wood it appears as masses in sections where cell texture has been destroyed. Where uraninite has replaced the cell walls (fig. 32), pyrite cubes, now surrounded and partially corroded by uraninite, may have grown from lumens. Pyrite veins in massive uraninite were probably formed by filling shrinkage cracks in the uraninite. Coalified wood containing minute blebs of pyrite is cut by some late calcite veins that contain pyrite (fig. 28). In sections where cellular matter has been entirely mineralized, pyrite has replaced many cell walls (fig. 27). Pyrite is rare outside fossil wood, but does cement some sand grains.

Marcasite is relatively rare and is found as irregular blebs in fossil wood and in sandstone.

Chalcopyrite has replaced walls of cells (fig. 29) and is found as anhedral crystals in calcite in fossil wood. It has also partly replaced feldspar grains in the sandstone (fig. 30).

Galena occurs as minute blebs in uraninite in fossil wood and as anhedral to subhedral crystals in calcite (fig. 33). It also occurs with uraninite in the sandstone cement.

Calcite was present in the original sediments as limestone beds and as limestone grains in the sandstone. More calcite may have been introduced to form the calcite cement, or this cement may have been produced by recrystallization of calcite already present. Much of the calcite was recrystallized or emplaced after the formation of the metallic minerals.

In fossil wood calcite has filled lumens in portions where the cell walls are uraninite, pyrite, or chalcopryite (figs. 27, 29), and veinlets of calcite cut across pyrite and uraninite (figs. 32, 28).

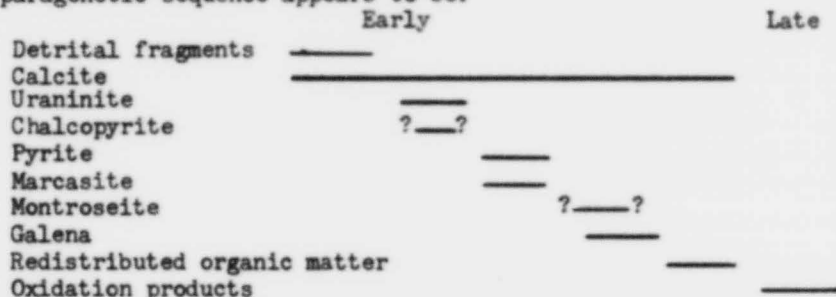
Barite is rare and occurs as red euhedral blades in calcite which has veined the fossil wood.

### Oxidation

Oxidation of the minerals of the ore zone has resulted in the formation of carnotite on the outcrop and of thenardite ( $\text{Na}_2\text{SO}_4$ ) as a fluffy white coating in places on the mine walls.

### Paragenesis

The paragenetic sequence appears to be:



### Climax School Section mine

The Climax Uranium Company mine on the school section, 32, T. 26 S., R. 21 E., Grand County, is in the Moss Back member of the Chinle formation. The uranium ore is closely associated with plant remains which were deposited in a shallow northwest-trending channel. The channel filling is mostly green shale up to 4 feet thick with scattered lenses and thin beds of sandstone and siltstone. Two systems of fractures, one trending N. 15° W. and dipping steeply northeast, and a second trending N. 25° E. and dipping steeply southeast intersect the channel. Small, lens-shaped, high-grade, uraninite-bearing ore bodies occur where the northwest-striking fractures intersect sandy, carbonaceous pockets in the channel. In addition to the pods of uraninite-bearing ore, stringers and coatings of secondary uranium minerals occur paralleling the bedding planes and the fracture planes.

The adit trends approximately east, and drifts on either side have followed the channel where it was intersected approximately 35 feet east of the portal. The main adit has been continued some 150 feet beyond the channel (October, 1957) but the green layers become barren east of the channel, and no more ore was encountered. Drilling from the top of the mesa has indicated ore approximately 35 to 40 feet east of the adit heading. Further development may disclose the relationships of ore, fracturing, and channel structure.

### Lithology and organic material

The rock immediately below the ore-bearing shale is a pink to gray, fine-grained sandstone containing major quartz, minor feldspar, and accessory mica, zircon, tourmaline, and magnetite. The cement is mostly clay and sericite with some calcite and hematite. The pink color of the rock is due to a thin coating of hematite around many of the grains and to grains which have been partially replaced by hematite. Many of the fragments of feldspar and mica contain veinlets of hematite along cleavage planes. The sandstone grades upward into shale, and a zone about a foot thick is of interbedded layers of pink sandstone and green shale.

The emplacement of ore was controlled by the localization of woody matter in pods in the green shale-sandstone channel filling. At the present time, very little carbonaceous matter is visible either megascopically or microscopically in the ore lenses. However, the cell texture has been preserved where the organic matter was replaced by minerals. The woody fragments vary in size from a millimeter to several centimeters. These fragments were deposited with sand in lenses up to 2 feet thick and 3 or 4 feet in the other two dimensions. The sandy lenses grade outward into green shale.

Above the shale layer is a fine-grained, clay-cemented, white sandstone containing major quartz and coalified wood fragments, minor feldspar, and accessory mica. The pieces of fossil wood have been flattened parallel to the bedding, and bent and twisted in other dimensions. In the plane paralleling the bedding the fragments are up to 5 inches across but they do not exceed 0.5 inch in thickness. All of the carbonaceous matter in the white sandstone is barren. Except for the fragments of fossil wood, the sandstone is very well-sorted and has little pore space.

### Uranium and associated minerals

The principal uranium mineral in the Climax mine is uraninite which replaces parts of the woody fragments and cements, and replaces (figs. 34, 35) the sandstone surrounding the wood. As the sandstone grades into shale uraninite becomes scarcer and more disseminated and finally is completely absent. Probably the porosity of the sand permitted freer passage of uranium-bearing solutions than did the finer-grained sediments. The abundant organic matter was at least partly responsible for the reduction and precipitation of uranium.

The cell texture of the wood has been preserved to varying degrees where uraninite has replaced cell walls (fig. 6). In some sections uraninite has replaced carbonaceous matter almost completely (Fig. 37) with only faint remnants of cell structure remaining. The most common occurrence of uraninite in replaced wood is as tiny rounded blebs in calcite (fig. 38). The relation of these minute blebs to the original plant structure is not known. They are seen in longitudinal sections of the fossil wood, and the same sections contain solid masses and stringers of uraninite.

Uraninite occurring along crystal faces in calcite was either deposited alternately with calcite (fig. 39) or else it penetrated along crystal faces of previously existing calcite (fig. 40). Alternating layers of uraninite

and calcite shown in figure 39 suggest open space filling. Pyrite crystals were deposited first, followed by uraninite and calcite precipitated alternately. Late calcite penetrated along the boundary between pyrite and uraninite, corroding the pyrite.

Figure 41 shows a crystal of pyrite which was veined by uraninite and subsequently partly replaced by calcite which did not replace the uraninite. Also shown are remnants of longitudinal sections of wood cells in which the uraninite outlines the cell walls.

In a few fragments of fossil wood, pyrite fills the lumens, and calcite or uraninite replaces the cell walls. Irregular patches and subhedral crystals of pyrite are scattered throughout replaced wood. Pyrite occurs as anhedral to subhedral crackled masses which were probably deposited as open space fillings (fig. 39). Many cracks are filled by uraninite and calcite.

In places sand grains are cemented wholly or in part by pyrite. In sections where pyrite, along with uraninite and calcite, is the cement the pyrite generally occurs as subhedral to euhedral crystals or rounded anhedral masses adjacent to the detritals and is rimmed by uraninite, with calcite filling the remaining space between grains. Rarely, pyrite occurs at the interface between uraninite and calcite or crystals occur disseminated in uraninite. Pyrite crystals have penetrated detritals, but extensive replacement of detritals is rare. A few euhedral pyrite crystals have replaced uraninite (fig. 42). Pyrite also occurs in veinlets of late calcite that cut massive uraninite.

Galena is quantitatively unimportant, but it is scattered throughout all sections that contain uraninite; its commonest occurrence is as small anhedral to euhedral crystals disseminated in uraninite (fig. 43). It is also found in calcite that replaces wood or cements detritals. Rarely galena has replaced parts of detrital grains; a few masses and crystals of galena are as much as 1 millimeter in greatest dimension, but most are much smaller.

Copper minerals are rare and were found only in the sections of replaced fossil wood. Chalcopyrite, the most abundant of the copper minerals, occurs mainly as euhedral to anhedral crystals disseminated in calcite (fig. 35), and it has partly replaced galena in some sections. Bornite is very rare and is found as blebs disseminated in calcite and as partial replacement of chalcopyrite. Both chalcopyrite and bornite have been partially oxidized with subsequent formation of covellite in veinlets through the other copper minerals and in nearby uraninite (fig. 44).

Laths and rounded masses of specular hematite were also found in calcite-replaced fossil wood. No paragenetic relations to other metallic minerals were observed.

Vanadium appears to be concentrated in vanadium clay in the outer portions of the sandy pods. No montroseite was observed; however, it may well be present considering the similarity of the mineralogy of the Climax mine to that of the Adair mine in which montroseite was found, and in consideration of the vanadium content of the high grade, low clay portions of the ore assayed (table 2).



Calcite is the most common nonmetallic cementing material in the immediate vicinity of the ore, and it has replaced many parts of fossil wood. Cell texture has been retained only where uraninite has replaced cell walls and other parts of the cell structure (fig. 36). The calcite which encloses uraninite is fairly coarse-grained and appears black because of the included uraninite whereas barren calcite is also coarsely-crystalline, but white. Even where the two varieties are in contact, each crystal is always either white and barren, or black and uraniferous.

Calcite is most abundant in the sandy lenses where uranium is concentrated. This is probably due to the fact that these portions were more permeable, with pore spaces not already occupied by rock flour and clay. Calcite, along with uraninite and pyrite, cements detrital grains. As the sediment becomes finer-grained toward the edges of the lenses, calcite becomes scarcer, although some is present in the shale and siltstone as irregular, scattered patches. No limestone pellets were observed in the sandstone although calcite has partly replaced many of the detrital grains.

Red, euhedral blades of barite were found in calcite-replaced wood. The barite crystals are fresh and uncorroded and were probably precipitated at about the same time as the enclosing calcite. No relationship to minerals other than calcite was observed.

In one section several veinlets of colorless chalcedony in sandstone were observed.

#### Oxidation

Oxidation of the Climax ore has resulted in the formation of beta-zippeite (figs. 45, 46, 47), andersonite, and boltwoodite. All ore mined to date (October, 1957) contains at least small amounts of secondary uranium minerals. All three occur intimately associated with gypsum, but not with each other. Beta-zippeite and andersonite are found as stringers and veinlets parallel to the bedding and along nearly vertical fracture planes. Beta-zippeite is more abundant and is more common in sandy zones, but andersonite is more common in siltstone and shale. Boltwoodite is rare and is found as veinlets in sandstone.

Gypsum is common throughout the sandstone lenses, and, in places, it cements detrital grains. It also occurs as veinlets in sandstone with and without the secondary uranium minerals.

Fine-grained red hematite is scattered throughout the rock, particularly in the sandy parts, where it has coated and replaced many of the grains.

#### Paragenesis

The positions of some of the minerals in the paragenetic sequence is quite obvious, but conflicting evidence, or lack of evidence, leaves the positions of others in doubt. In most instances pyrite appears to have been precipitated before uraninite (figs. 41, 44, 39). It appears most likely, however, that the pyrite crystals shown in figure 38 developed after the uraninite because the texture of the uraninite, inherited from fossil wood,

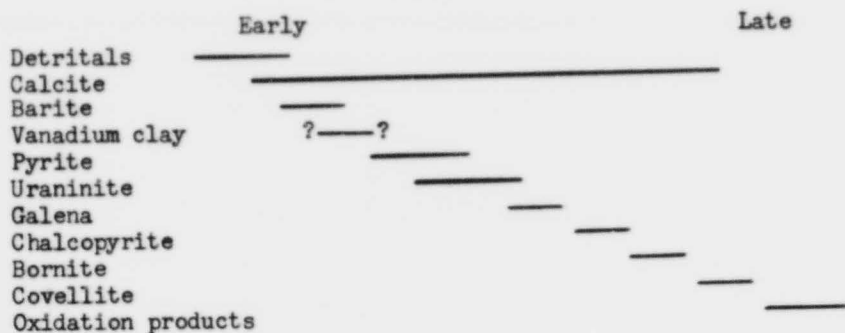
continues uninterrupted through the pyrite crystal. Pyrite shown in Figure 42 has replaced uraninite. Either there were two generations of pyrite, or deposition of pyrite and uraninite overlapped.

The paragenetic relation of galena is generally indeterminable, although a few veinlets of galena cut uraninite (fig. 40).

Calcite must have preceded uraninite in some sections since uraninite follows the crystal outlines of calcite (fig. 40). It is very likely that this texture is a result of alternating precipitation of uraninite and calcite. Veinlets of calcite cut across uraninite which has replaced cells (fig. 36). In sandy portions calcite has filled open spaces left after uraninite rimmed or replaced the grains (fig. 34).

Relative ages of chalcopryrite and bornite to uraninite and pyrite were determined indirectly. Bornite has replaced chalcopryrite which in turn has replaced galena. At least some of the galena was deposited later than uraninite and uraninite later than some pyrite, so that chalcopryrite and bornite are probably later in the sequence than uraninite and pyrite. Covellite, probably an alteration product of bornite and chalcopryrite, veins these two minerals and uraninite. However, intervening calcite contains no covellite.

The above observations have led to the following paragenetic sequence for the ore of the Climax School Section mine:



#### CHEMICAL AND RADIOMETRIC ANALYSES OF ORE

The samples assayed chemically and radiometrically (Table 2) were chosen either because they were representative of the typical high-grade ore studied in polished and thin sections or because the results could be used to estimate the state of equilibrium or disequilibrium of the ore. Probably none of the samples represents the average ore of any mine.

Generally the amount of uranium exceeds that of vanadium, but U/V ratio is highly variable. It is noteworthy that the U/V ratio for ore from the Moss Back member on the east side of the canyon is as much as 100 times greater than that for ore from the Moss Back on the west side. In general the uranium-vanadium ratio is reflected in the secondary uranium minerals present. Carnotite was observed in the Honeybee, Honeybee No. 2, and Adair mines whereas none was found in the Moss Back adit nor the Climax School Section

mine. An anomalous situation exists in the pit on the Canary claim where no carnotite was observed, although the U/V ratio is low. The common uranium secondary mineral is andersonite. Either the uranium in this area was oxidized and formed secondary minerals while the vanadium remained unoxidized, or else the oxidized uranium was introduced from some outside source.

Most of the samples are not in radiometric equilibrium. Most of the unoxidized or partly oxidized ores are low radiometrically while the oxidized ores are high radiometrically.

The uranium copper ratio is extremely variable because the copper content remains small while the uranium content varies from sample to sample.

#### PHYSICAL CHARACTERISTIC OF THE ORGANIC MATERIAL

Organic matter from four of the Cane Creek mines was isolated by hand picking under a binocular microscope.

#### Sample locations and physical descriptions

Results of physical tests on the samples described below are given in Table 3:

(1) Honeybee mine: Black lenses and layers in biotite schist. Mostly massive, black, hard, dull, rarely harder and shiny. Much uraninite, chalcopryite; minor pyrite, galena and gangue minerals.

(2) Honeybee mine: Thick veinlet of solid black. Mostly dull, hard, but includes veinlets of shiny black. Much uraninite; minor chalcopryite, calcite, galena, pyrite.

(3) Honeybee mine: Brownish-black material disseminated in biotite schist. More altered and less pure than (1). Soft, dull. Some andersonite, uraninite, chalcopryite, gangue.

(4) Honeybee No. 2 mine: Black; from friable, poorly cemented sandstone in fault zone. Soft, brittle, shiny. Contains a few detrital grains.

(5) Adair mine: Coalified wood. Hard, brittle, dull. Minor calcite, pyrite, uraninite.

(6) Moss Back adit: Black material at edge of log. No woody texture remains in material sampled. Hard, dull. Much uraninite; minor pyrite, galena.

#### Testing procedures

The following tests were performed on the samples described above:

I. A. Samples dried at 140° for one hour. Cooled and weighed.

B. Remainder allowed to stand in CS<sub>2</sub> for 72 hours. Filtered, washed with CS<sub>2</sub>, dried, and weighed.



Table 3

## RESULTS OF PHYSICAL TESTS ON PYROBITUMEN

Sample	I			II				III	
	%A	%B	%C	%A	%B	%C	%D	A	B
(1)	2.41	nil*	12.40	1.88	66.91	10.29	21.01	Does not burn nor fuse	Burns with red glow. Infusible#
(2)	2.62	nil*	21.79	1.83	74.19	22.17	1.81	Burns with red glow. Infusible#	Burns with red glow. Infusible
(3)	10.35	nil*	29.16	7.27	49.74	24.51	18.44	Burns with red glow. Infusible#	Burns with red glow. Infusible
(4)	12.88	nil*	44.94	10.08	30.77	32.72	26.42	Burns with red glow. Infusible#	Burns with red glow. Infusible
(5)	1.89	3.00	83.32	1.66	2.51**	97.00	1.34	Burns with smoky yellow flame. Infusible#	Burns with smoky yellow flame. Infusible
(6)	5.17	nil*	25.87	3.45	77.56	18.44	0.45	Burns with red glow. Infusible#	Burns with red glow. Infusible.

See text for detailed explanation of tests and properties.

\* Less than 0.01%

\*\* = % increase in weight.

# Material does not support combustion outside of flame.

- C. Residue from B ignited at 810° C. for one hour.
- II. A. Samples dried at 110° C. for one hour. Weighed.
- B. Boiled in 1:3 HNO<sub>3</sub> for one hour. Filtered, washed, dried, and weighed.
- C. Ignited at 810° C. for one hour. Weighed.
- III. A. Fragment placed in alcohol flame for one minute.
- B. Fragment placed in blowtorch for one minute.

#### Calculations and results

##### Procedure I

A.  $\frac{\text{Weight loss at } 140^{\circ} \text{ C.}}{\text{Weight of original sample}} \times 100 = \% \text{ loss at } 140^{\circ} \text{ C.}$

Remarks: Results were always higher than loss at 110° C. due to loss of additional water (such as water of crystallization of one or more minerals), loss of volatile organic constituents, and/or loss of CO<sub>2</sub> from partial decomposition of carbonates.

B.  $\frac{\text{Weight of residue from A} - \text{weight of residue from B} \times 100}{\text{Weight of original sample}} = \% \text{ dissolved in CS}_2$

C.  $\frac{\text{Weight of residue from B} - \text{weight of residue from C} \times 100}{\text{Weight of original sample}} = \% \text{ loss on ignition}$

Remarks: Difference between this and II-C is probably due to presence of uraninite and sulfides that were oxidized, causing increase in weight, and to the presence of carbonates that partially or wholly decomposed, causing decrease. Therefore, this determination has little meaning without determination of the amount of original uraninite, sulfides, and carbonate.

##### Procedure II

A.  $\frac{\text{Loss in weight}}{\text{Weight of original sample}} \times 100 = \% \text{ of adsorbed water.}$

Remarks: Sample preparations and tests were carried out during damp weather.

B.  $\frac{\text{Weight of residue from A} - \text{weight of residue from B} \times 100}{\text{Weight of original sample}} = \% \text{ dissolved in 1:3 HNO}_3$

Remarks: Loss consists of carbonates (mainly calcite, ankerite, and andersonite), uraninite, and sulfides (mainly pyrite, marcasite, galena, and chalcopyrite). Some organic material may have dissolved. One sample increased in weight, probably due to the formation of organic nitrates; other samples may have reacted similarly, but the increase was more than offset by the loss by solution of other constituents.

C.  $\frac{\text{Weight of residue from B} - \text{weight of residue from C} \times 100}{\text{Weight of original sample}} = \% \text{ loss on ignition}$

Remarks: Indicates approximate percentage of organic constituents.

D.  $\frac{\text{Weight of residue from C}}{\text{Weight of original sample}} \times 100 = \% \text{ ash}$

Remarks: Consists of quartz, feldspar, mica, clay, barite, etc.

### Procedure III

A. and B. Indicates whether material fuses and/or burns in the respective flames and whether the material supports combustion.

### Discussion

The organic materials found in the various Cane Creek mines are all pyrobitumens according to Abraham's classification (Abraham, 1945). According to this classification pyrobitumens are "native substances of dark color; comparatively hard and non-volatile; composed of hydrocarbons, which may or may not contain oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being infusible and relatively insoluble in carbon disulfide. Scope: This definition includes the asphaltic pyrobitumens (elaterite, wurtzilite, albertite, and impsonite), also the non-asphaltic pyrobitumens (peat, lignite, bituminous coal and anthracite coal), and their respective shales." All of the samples tested from Cane Creek are infusible, and only one is even slightly soluble in carbon disulfide. The distinction between asphaltic pyrobitumen and non-asphaltic pyrobitumen is more difficult to make since the oxygen content is generally determined by difference after determination of hydrogen, carbon, nitrogen, sulfur, water, and ash; and most of these were not determined on the Cane Creek materials. The coalified wood from the Adair mine is obviously non-asphaltic. The tested material from the Moss Back adit came from a 1- to 2-inch layer surrounding a large fossil log and was undoubtedly derived from the log. Lack of cell structure is no criterion whatsoever since many fossil plant-remains show no remnants of cells. The remaining samples, therefore, may be asphaltic or non-asphaltic pyrobitumens although they closely resemble the non-asphaltic material from the Moss Back adit. It is the opinion of the writer that most, if not all, of the organic material is the product of alteration and redistribution of organic matter deposited in the original sediments. During the processes of burial, compaction, folding, and faulting, metamorphosis of the organic detrital matter took place, resulting in many different chemical-physical changes including loss of volatile constituents, carbonization, polymerization, distillation and condensation, and plastic- and liquid-state flow. In any case, the end result is the production of the present pyrobitumens. The term "asphaltite" which has been used to describe some of the substances tested is an incorrect one according to Abraham's classification.

### COLOR DIFFERENCES IN THE CUTLER FORMATION

The various differences in color of the Cutler formation in and near the Honeybee and Honeybee No. 2 mines were studied by means of thin section, quantitative chemical analyses, and semi-quantitative spectrographic analyses. The chemical and spectrographic analyses are given in Table 4. The samples selected for analysis were collected from the fault zone and from rocks about 75 feet away from the fault.

The term "unbleached rock" is used in this paper to mean rock that is some shade of red, and "bleached rock" refers to rock that is lighter in

Table 4

Chemical and Spectrographic Analyses of "Bleached" and "Unbleached"  
Cutler rock

	(1)	(2)	(3)	(4)	(5)	(6)
<u>Chemical*</u>						
%Fe(III)	1.05	2.01	1.67	3.38	6.31	21.42
% Fe(II)	0.04	0.06	0.36	0.15	0.98	1.09
<u>Spectrographic#</u>						
%						
Si	M	M	M	M	M	M
Al	7.	7.	7.	7.	M	7.
Fe	.7	1.5	.7	1.5	1.5	7.
Mg	.7	1.5	3.	1.5	1.5	1.5
Ca	.7	.7	7.	M	.3	.7
Na	1.5	1.5	3.	3.	1.5	1.5
K	3.	3.	3.	3.	7.	7.
Ti	.15	.15	.03	.15	.3	.3
Mn	.007	.015	.07	.03	.03	.03
B	tr	0	0	.003	.007	.007
Ba	.07	.07	.07	.07	.03	.03
Be	0	0	.00015	0	.0003	.0003
Co	0	0	.0007	.0007	<.005	<.005
Cr	.0015	.0015	.0015	.003	.007	.007
Cu	.0015	.0015	.003	.003	.007	.007
Ga	.0007	.0007	.0007	.0007	.0015	.0015
Ge	0	0	0	0	0	<.005
La	0	0	0	0	0.003	.003
Mo	0	0	0	0	.0007	.0007
Nb	tr	tr	0	0	.0015	.0015
Nd	0	0	0	0	tr	tr
Ni	.007	.007	.0015	.0015	.003	.003
Pb	0	.0015	.0015	.0015	.0015	.003
Sc	.0007	.0007	0	.0015	.003	.003
Sr	.015	.015	.03	.03	.03	.03
U	0	0	0	0	.15	.7
V	.007	.007	.003	.007	.07	.15
Y	0	.0015	.0015	.0015	.003	.003
Yb	.00015	.00015	.00015	.0003	-	-
Zr	.015	.007	.007	.015	.03	.03

Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3 etc. Sixty percent of the reported results may be expected to agree with the results of quantitative methods.

Symbols used are: -: not looked for; 0: looked for but not detected; M: major constituent, greater than 10%; tr: near threshold amount of element.

Looked for, but not detected: P, Ag, As, Au, Bi, Cd, Ce, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pr, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, W, Zn.

\* by Brown Laboratories, Grand Junction, Colorado

# by U. S. Geological Survey, Denver Laboratory, reported in TDS-8776 and TDS-8800.

- (1) Honeybee No. 2 mine, white sandstone along fractures at end of adit.
- (2) Red sandstone associated with (1).
- (3) White Cutler arkose from outcrop, 40 feet south of Honeybee No. 2 mine.
- (4) Red Cutler arkose associated with (3).
- (5) Honeybee mine, green biotite schist in fault.
- (6) Red biotite schist associated with (5).

color, typically white, light-gray, or green. Bleached rock in the Cutler formation and in other formations in Cane Springs Canyon is widespread and is by no means confined to the ore zones.

In each of the three pairs of rock analyzed, the red (unbleached) and white or green (bleached) rocks were in patches a few tenths of an inch to a few inches apart. The bleached and unbleached portions were carefully hand-separated and ground.

The quantitative analyses show that the change from red color to a lighter color was caused chiefly by removal of Fe(III) which was present as hematite. The possibility of reduction to Fe(II) with the Fe(II) remaining in the rock was considered, but the analyses show that the amount of Fe(II) is essentially the same in bleached and unbleached rock. (Chemical analyses of Entrada sandstone from the Rifle mine, Garfield County, Colorado, show that a similar change took place where red sandstone was bleached along fractures). Since the Fe(III) hydrolyzes readily and reprecipitates as the hydrous oxide, the removal of the hematite probably involved reduction of the iron to Fe(II) which does not readily hydrolyze and which was removed in solution.

The large amount of Fe(III) remaining in sample 5, a bleached sample (Table 4), is explained by the presence in the rock of a large amount of biotite which imparts a green color to the rock and contains both Fe(II) and Fe(III). The biotite has remained unaffected by the solutions which removed the hematite. Sample 6 contained about the same percentage of biotite, but the green color was masked by the hematite.

The distribution of bleached and unbleached country rock is irregular. In places layers of white are intermixed with layers of red; in other places rounded or lens-shaped patches of white may be surrounded by red sandstone. The white patches and layers do not appear to be related to any fracture pattern. Here hematite may never have been deposited or hematite may have been deposited and later removed. Evidence favoring either hypothesis is lacking.

Specimens 3 and 4 are from an area in the Honeybee No. 2 mine in which the bleaching is definitely fracture-controlled (fig. 16). Solutions travelling along irregular fractures in and near the fault caused bleaching in zones beginning at the fracture surfaces and extending up to several inches on each side.

The hematite in the biotite schist is distributed quite irregularly, but is mostly in lenses and streaks with the longer dimensions parallel to the planes of schistosity which in turn parallel the fault. Most fractures are healed and are not visible either megascopically or microscopically.

In the vicinity of the fault, the rock is definitely less red than at a distance from the fault. Evidently the solutions causing the bleaching in the fault-zone travelled through the open spaces produced by faulting. The association of the bleaching solutions to ore-bearing solutions is unknown; both followed fractures in the fault zone and were, therefore, of post-fault age. Ore-bearing solutions may have produced the bleaching, or the bleaching may have been produced by other solutions passing through the

same zone before and/or after mineralization. It is doubtful that ore-bearing solutions were responsible for the differences in color in the country rock since these differences were found in the Cutler formation miles away from the faulted area.

The gray-green coloration in the lower part of the Chinle, which transects both bedding planes and lithologic variations within beds, is reported to be of maximum intensity on the northeast flank of the Cane Creek anticline in the vicinity of the Cane Creek fault (McRae, 1958). This alteration was not studied by the author since the major ore bodies on the east side of Cane Springs Canyon are not in the Chinle.

#### SUMMARY

1. The uranium was introduced into the Cane Springs Canyon area after formation of the structural features of the area. Baker (1933) says that the present structural features were essentially formed by the end of Cretaceous time. The age determination by J. L. Kulp dates the mineralization of the Honeybee mine as late Paleocene or early Eocene. The mineralization in the other mines is probably of the same age.

2. The deposits are vein-type and occur along faults and fractures.

3. The mineralizing solutions travelled through openings provided by faulting and fracturing. The solutions may well have come from below since all exposed formations from the Moss Back down contain uranium, but none has been found in formations above the Moss Back.

4. Uranium was precipitated by local reducing conditions produced by organic material and, possibly, by hydrogen sulfide.

5. The organic matter is now pyrobitumen, probably of plant origin, some of which migrated short distances in a fluid or plastic state.

6. Bleaching, due to removal of hematite, is more common near the faults. The bleaching in and near the fault zones is spatially related to the faults, as is the mineralization, but the two are not necessarily otherwise related to each other.



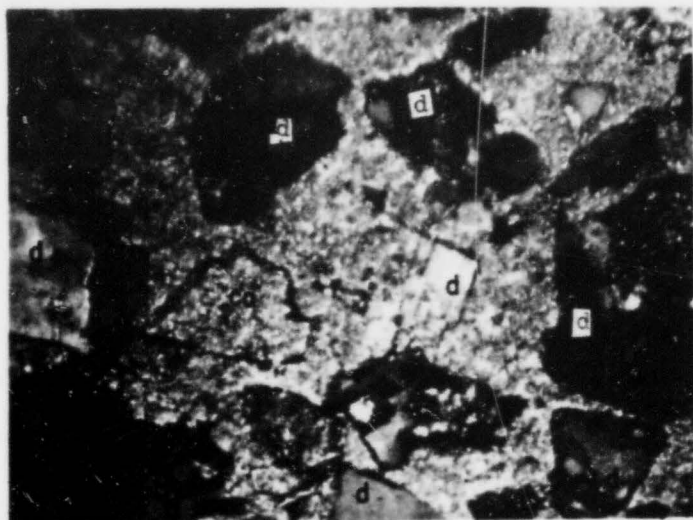


Fig. 5. Calcite-cemented sandstone in which calcite (ca) has partly or wholly replaced some of the detrital grains (d). Outline of replaced grains preserved by thin film of hematite. Honeybee mine. Thin section. Crossed Nicols. X107.



Fig. 6. Quartz-mica schist in fault zone. Honeybee mine. Thin section. X107.

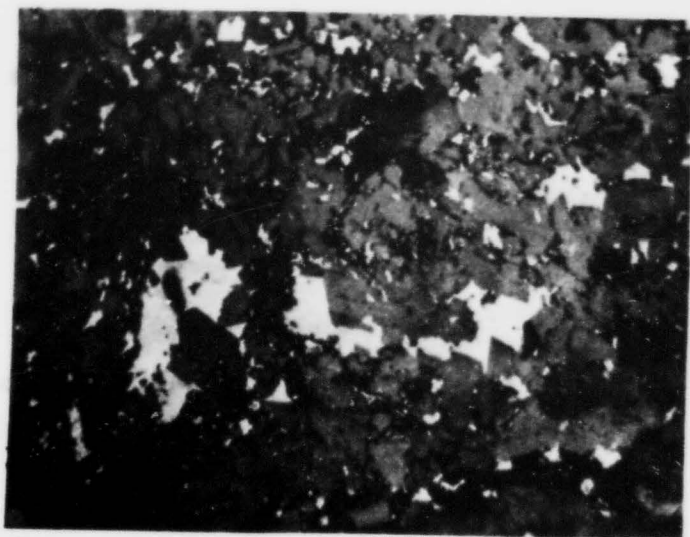


Fig. 7. Spaces between calcite crystals (medium-gray) filled with chalcopyrite (white). Honeybee mine. Polished section. X225.

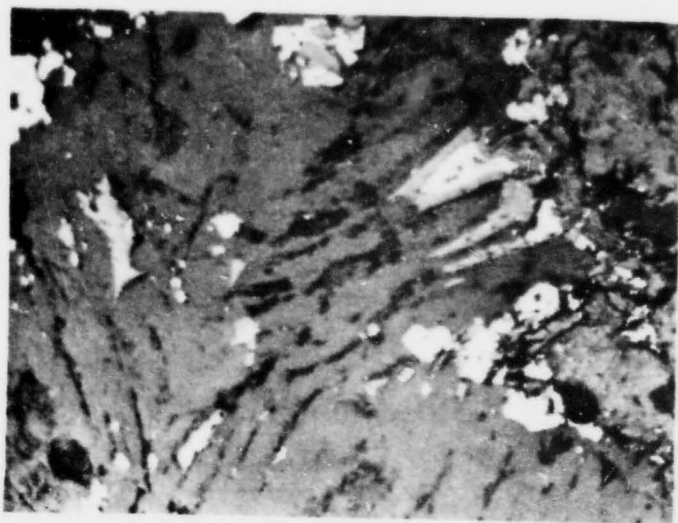


Fig. 8. Chalcopyrite (white) and uraninite (light-gray) as replacement of barite (medium-gray). Honeybee mine. Polished section. X225.

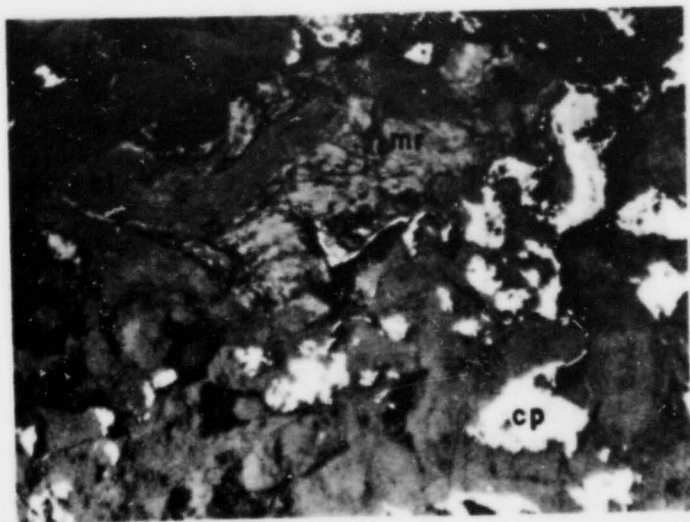


Fig. 9. Mass of montroseite (mr) which has replaced biotite (bi) along cleavage planes, veined by chalcopyrite (cp). Honeybee mine. Polished section. X135.

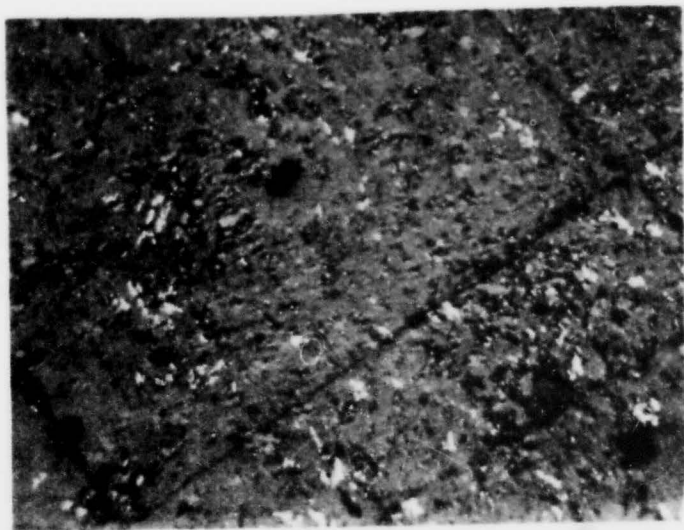


Fig. 10. Uraninite (light-gray blebs) and chalcopyrite (nearly white) in pyrobitumen matrix. Honeybee mine. Polished section. X225.

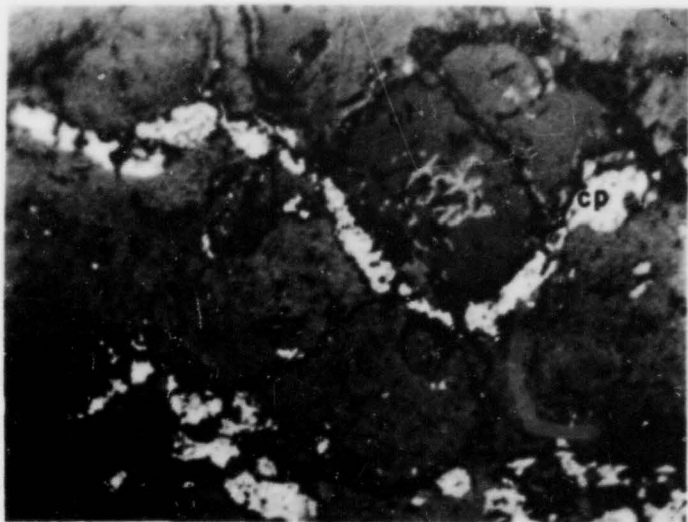


Fig. 11. Chalcopyrite (cp) veining submicroscopically intergrown uraninite-pyrobitumen (pb). Uraninite (light-gray) also replaces quartz grain (qt). Honeybee mine. Polished section. X225.

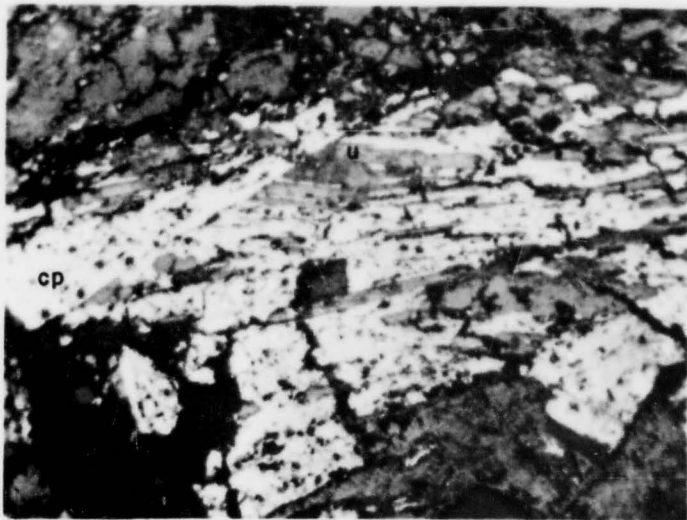


Fig. 12. Chalcopyrite (cp) and uraninite (u) pseudomorphs after barite. Chalcopyrite contains disseminated galena (lighter gray). Honeybee mine. Polished section. X225.

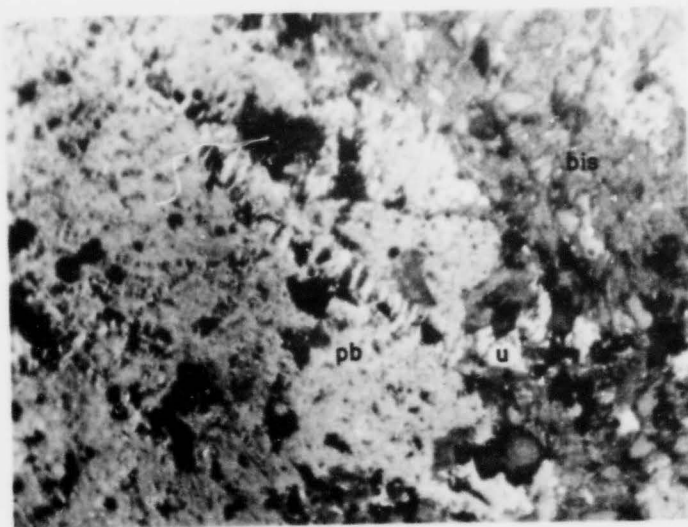


Fig. 13. Uraninite veinlet (u) extending from pyrobitumen (pb) into biotite schist (bi s). Black spots are pits in section. Honeybee mine. Polished section. X135.

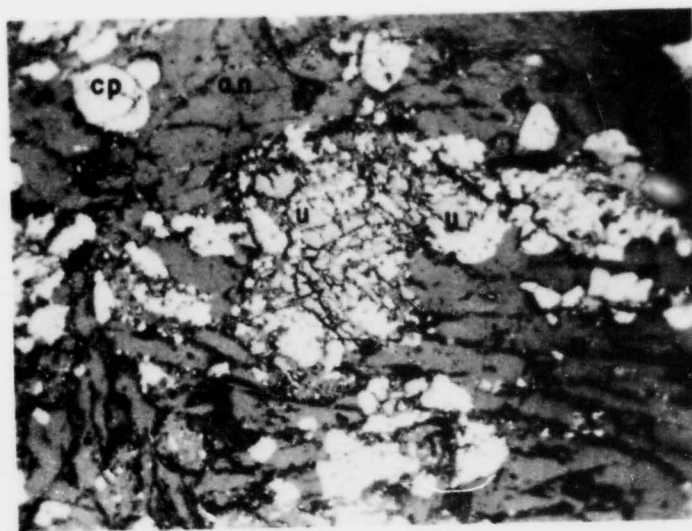


Fig. 14. Chalcopyrite (cp) and uraninite (u) in ankerite (an). Honeybee mine. Polished section. X225.



Fig. 15. Uraninite (medium gray) finely disseminated in pyrobitumen (slightly darker shade of gray) and ankerite (dark gray). Chalcopyrite (white) in barite (ba). From fault zone in Honeybee mine. Polished section X225.



Fig. 16. Honeybee No. 2 mine located along minor fault which strikes east and dips north.



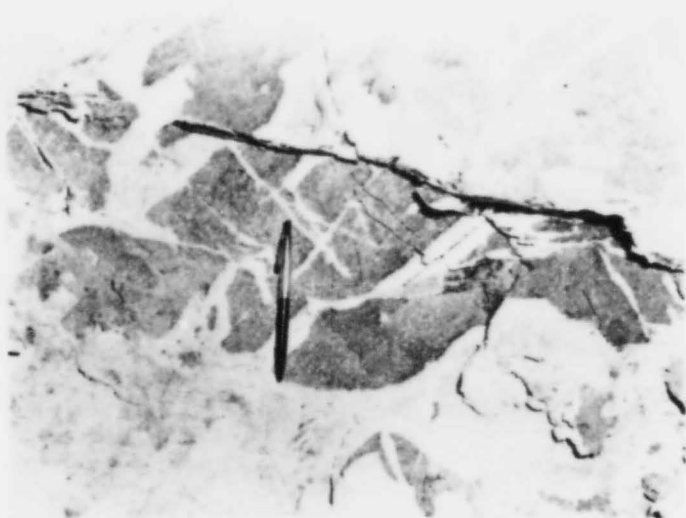


Fig. 17. Honeybee No. 2 mine. Ferruginous red sandstone (dark) has been bleached along fractures to low-iron, white sandstone.

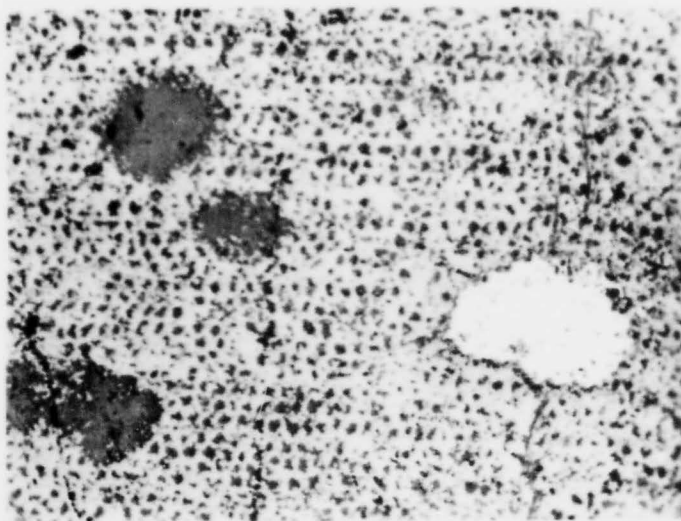


Fig. 18. Fossil wood replaced by uraninite (light-gray), calcite (dark-gray) and pyrite (nearly white). Note that the uraninite has filled or nearly filled most of the cell. Pyrite and irregular patches of calcite have destroyed the cell texture. Moss Back adit. Polished section. X135.

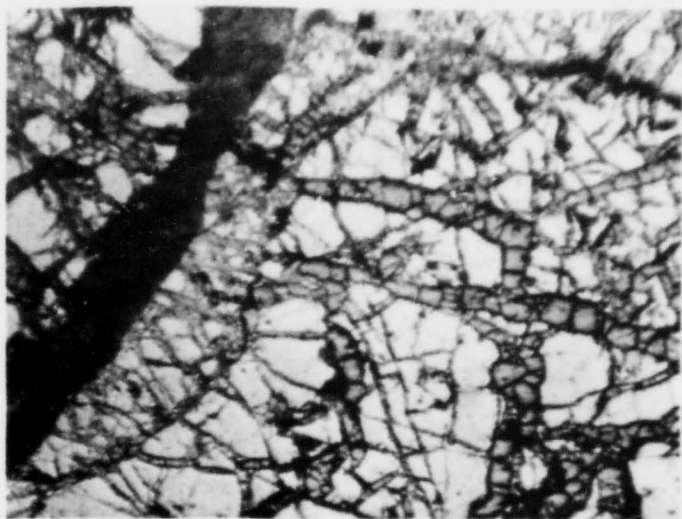


Fig. 19. Uraninite (light-gray) veined by organic matter (medium-gray). Widest dark veinlet is Beta-zippeite. Moss Back adit. Polished section. X47.

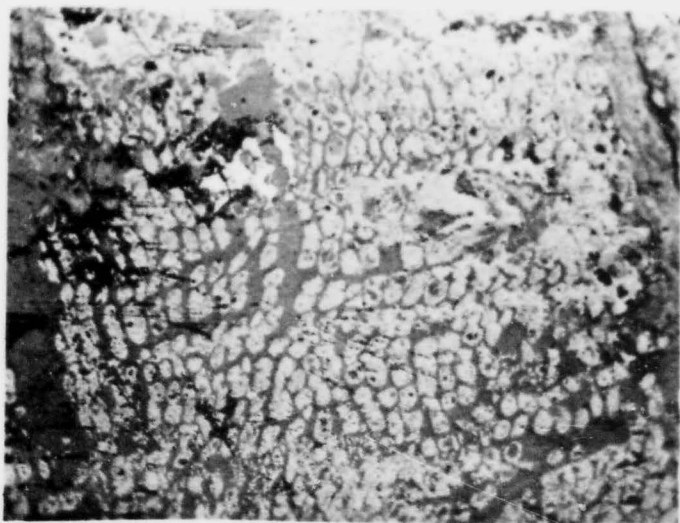


Fig. 20. Fossil wood in which uraninite (light-gray) has partly or wholly replaced the cells. The cell walls are calcite (dark-gray) and pyrite (white). The cell structure has been distorted or destroyed in some places. Moss Back adit. Polished section. X135.

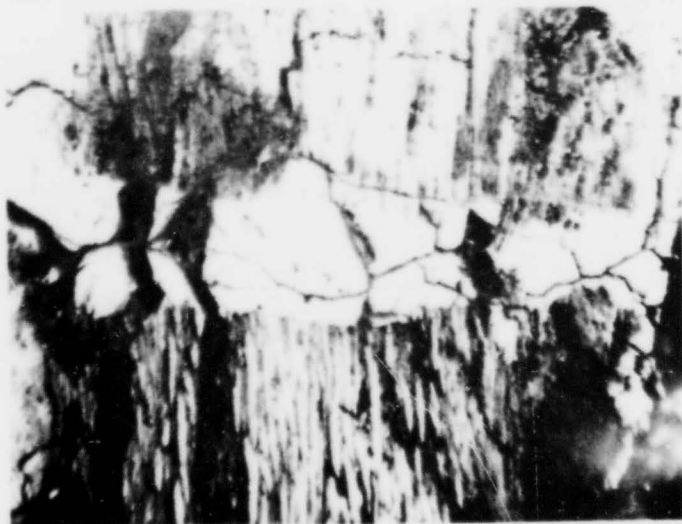


Fig. 21. Longitudinal section of fossil wood with cell structure preserved by pyrite (white). Veinlet of pyrite cuts across cell texture. Pyrite is partly altered to hematite (light-gray). Moss Back adit. Polished section. X47.

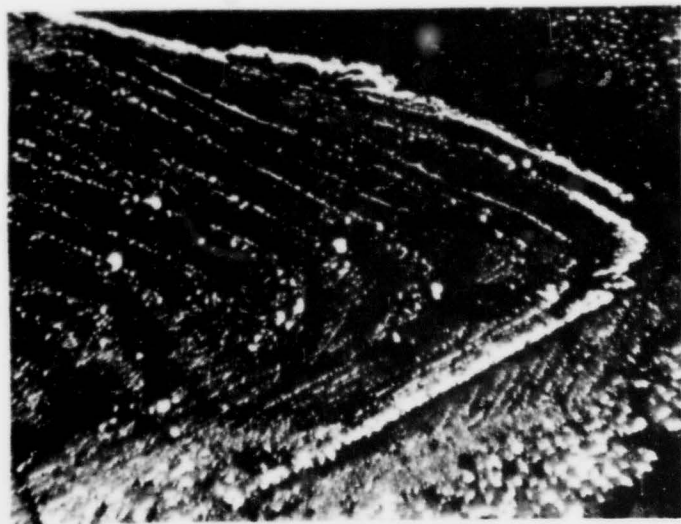


Fig. 22. Pyrite (white) which has precipitated alternately with calcite (medium-gray) on successive faces of growing calcite crystals. Moss Back adit. Polished section. X107.

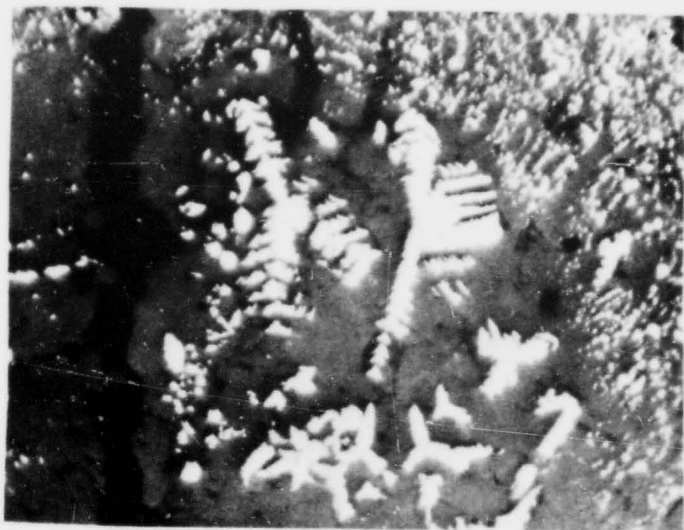


Fig. 23. Arborescent skeletal pyrite in calcite. Moss Back adit. Polished section. X135.

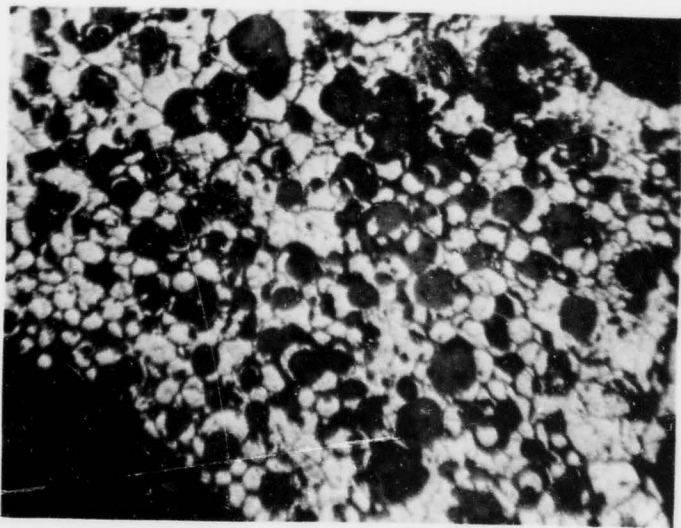


Fig. 24. Pyrite (light-gray) after fossil wood. Dark-gray is calcite. Moss Back adit. Polished section. X47.

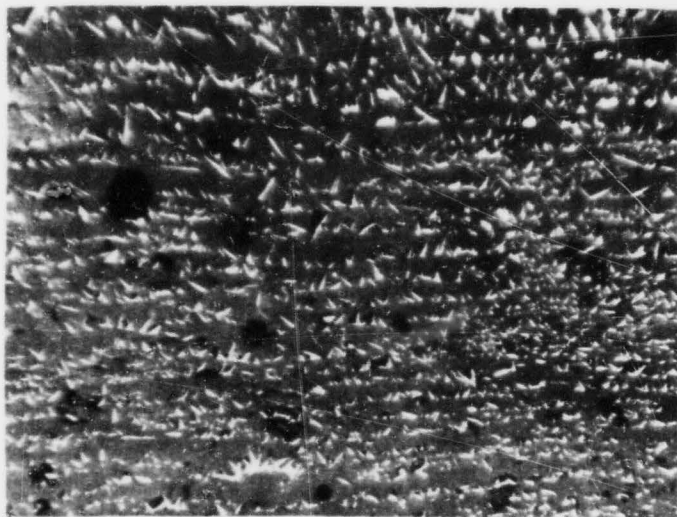


Fig. 25. Marcasite (light-gray) precipitated alternately with calcite (medium-gray matrix). Moss Back adit. Polished section. X107.

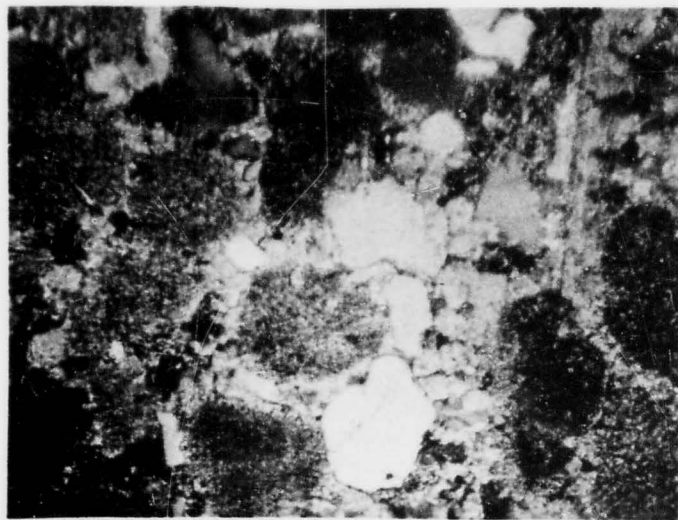


Fig. 26. Calcarenite. Adair mine. Thin section. Crossed Nicols. X107.

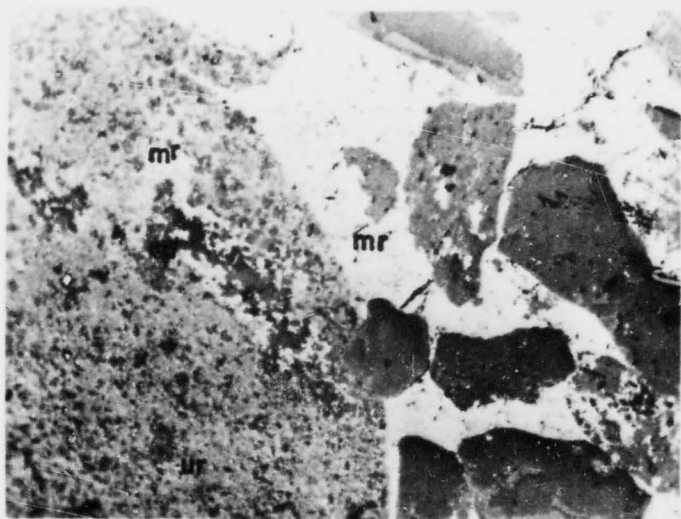


Fig. 27. Montroseite (mr) and calcite (ca) cementing sandstone. Uraninite (ur) has partly replaced argillaceous limestone grain which is veined by calcite and montroseite. Adair mine. Polished section. X135.

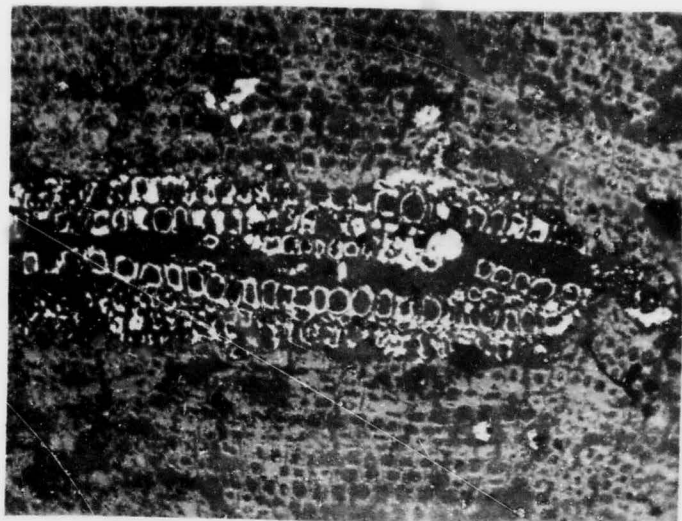


Fig. 28. Fossil wood in which uraninite (light-gray) and chalcopryrite (white) have replaced cell walls, and calcite (dark-gray) and pyrite (white) have replaced cell centers. Chalcopryrite and pyrite are same shade in figure. Black spots are pits in section. Adair mine. Polished section X135.



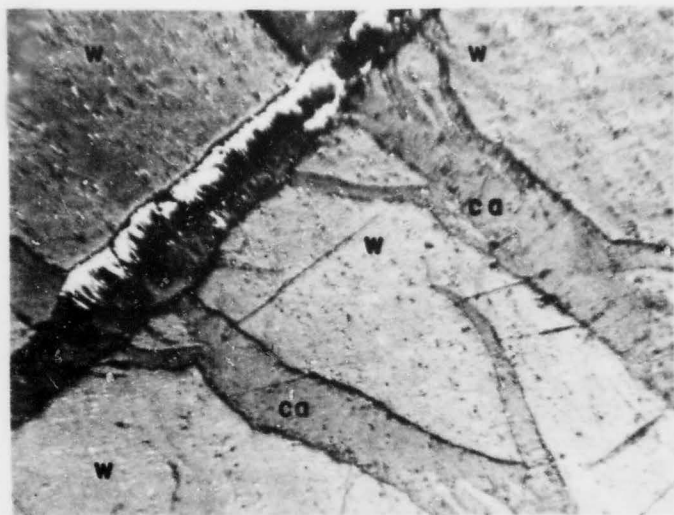


Fig. 29. Coalified wood (w) cut by calcite veins (ca) which are in turn cut by later calcite vein containing pyrite (white). Wood shows cell structure and contains minute pyrite blebs.

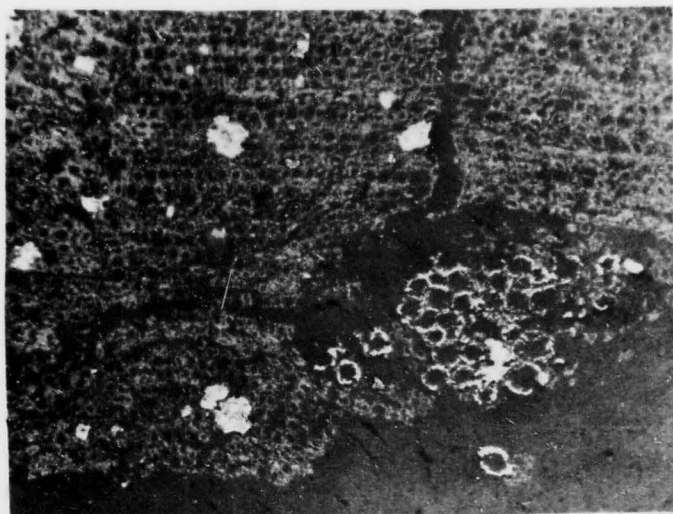


Fig. 30. Fossil wood replaced by uraninite (light-gray), chalcopryrite and pyrite (both white), and calcite (medium-gray). Chalcopryrite replaces cell walls in lower right. Pyrite masses enclose cell walls replaced by uraninite. Black spots are pits in section. Adair mine. Polished section. X135.

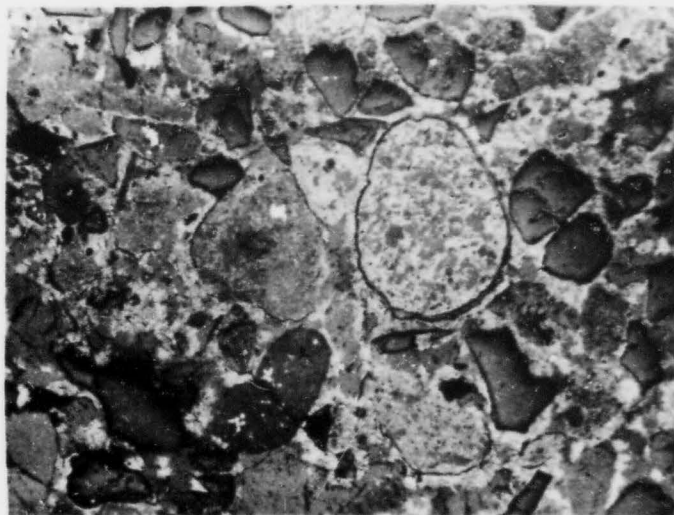


Fig. 31. Sandstone cemented by uraninite (light-gray) and calcite (medium-gray). Uraninite and chalcopryrite (white) have partly replaced many of the detrital grains. Adair mine. Polished section. X47.



Fig. 32. Sandstone cemented by montroseite (mr) which has also partly replaced detrital mica (mi) along cleavage planes. Adair mine. Polished section. X225.

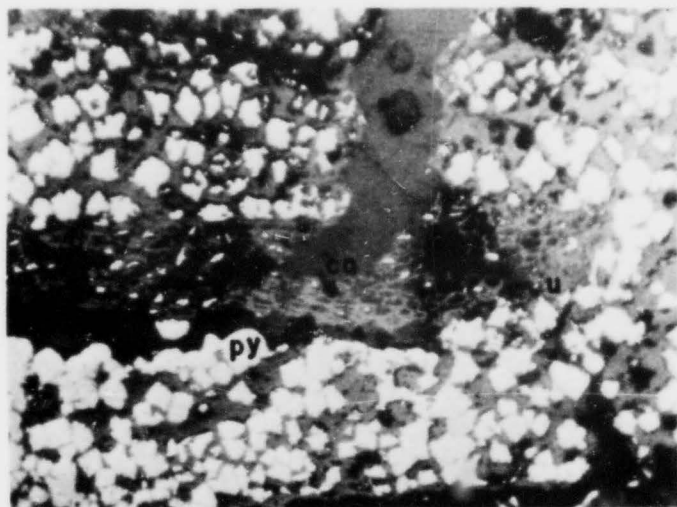


Fig. 33. Cell texture in fossil wood preserved in inner portion by uraninite (u) and calcite (ca). Cell texture destroyed where pyrite (py) crystals occur in uraninite. Adair mine. Polished section. X135.

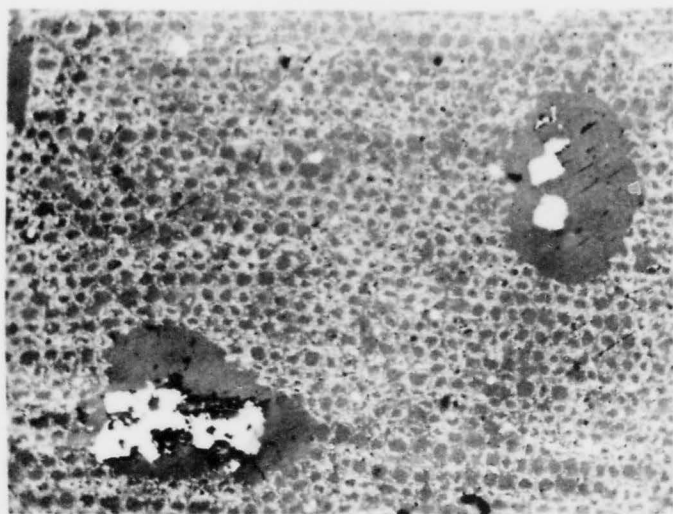


Fig. 34. Fossil wood replaced by uraninite (light-gray) and calcite (medium-gray). Galena (white) in calcite. Adair mine. Polished section. X135.

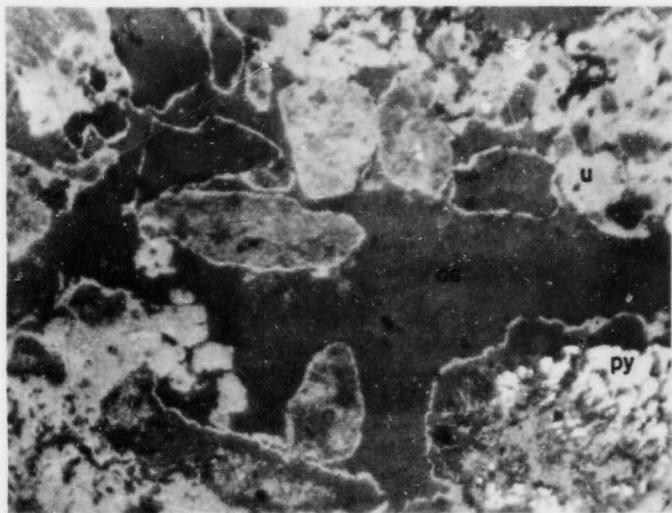


Fig. 35. Sandstone cemented by uraninite (u) and calcite (ca). Uraninite and pyrite (py) have partly replaced many of the detrital grains, and uraninite rims some grains. Climax School Section mine. Polished section. X135.

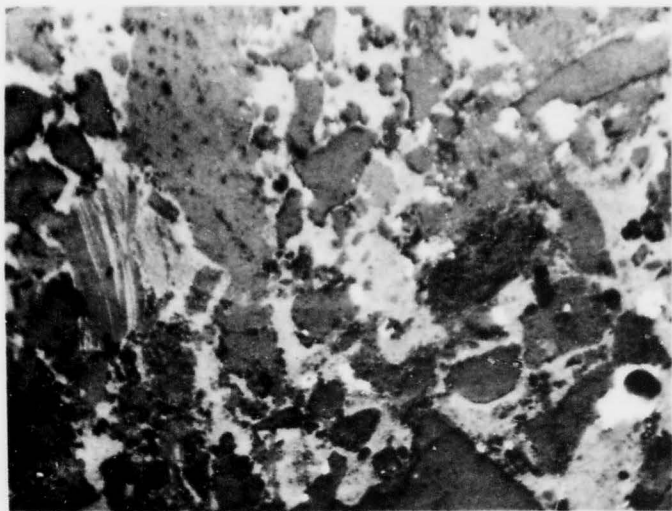


Fig. 36. Uraninite (light-gray), pyrite (white), and calcite (medium-gray) cementing sandstone. Climax School Section mine. Polished section. X135.

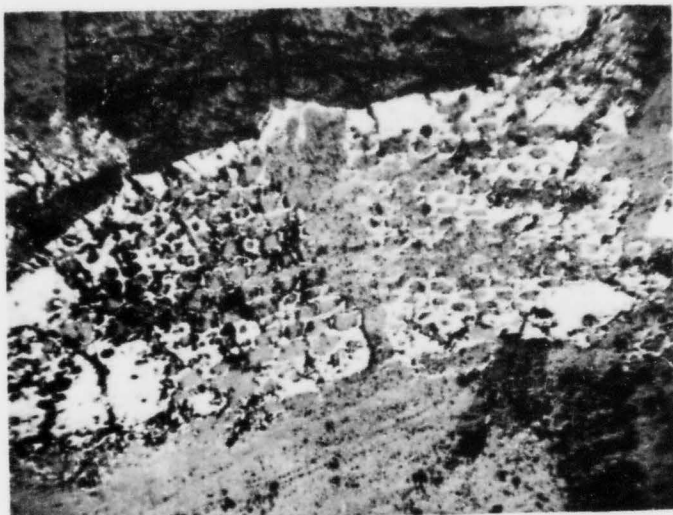


Fig. 37. Fossil wood. Cell walls have been replaced by uraninite (white). Remainder is calcite. Climax School Section mine. Polished Section. X35.

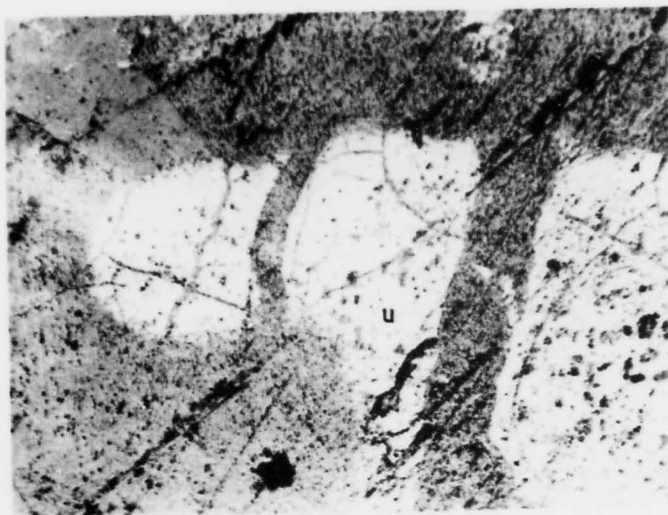


Fig. 38. Massive uraninite (u) cut by calcite (ca). Climax School Section mine. Polished section. X47.

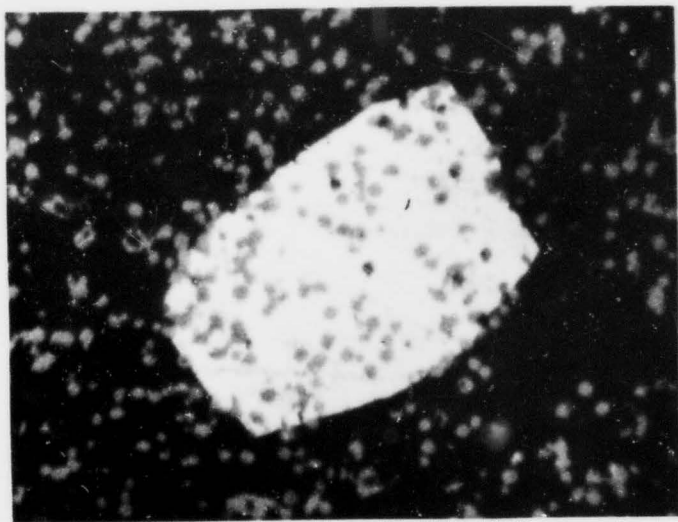


Fig. 39. Pyrite (white), uraninite (light-gray), and calcite (dark-gray) in fossil wood. Round blebs of uraninite penetrate the border of the pyrite crystal. Climax School Section mine. Polished section. X464.

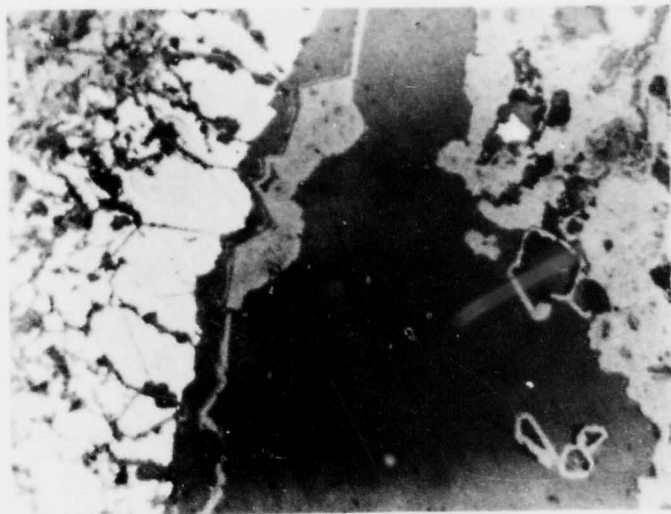


Fig. 40. Massive pyrite (white) veined by calcite (dark-gray) and uraninite (light-gray). Uraninite along vanished faces of corroded pyrite crystals and along faces of calcite crystals. Climax School Section mine. Polished section. X225.





Fig. 41. Uraninite (light-gray) along crystal planes of calcite (medium-gray). Climax School Section mine. Polished section. X135.

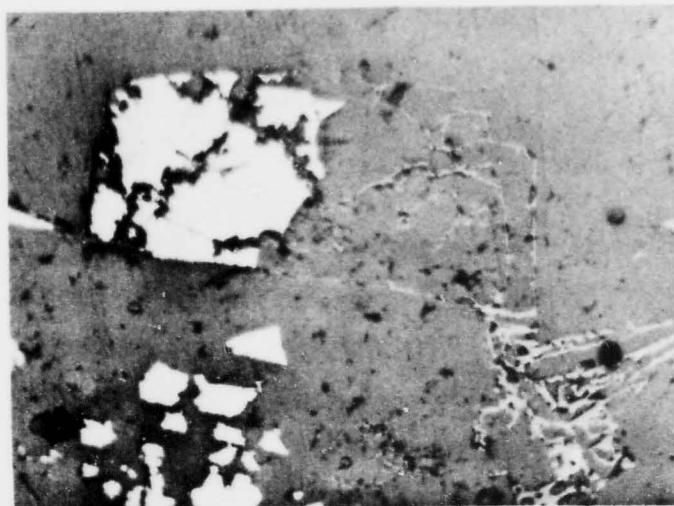


Fig. 42. Pyrite crystal (white) partly replaced by uraninite (light-gray) and calcite (medium-gray). Climax School Section mine. Polished section. X225.

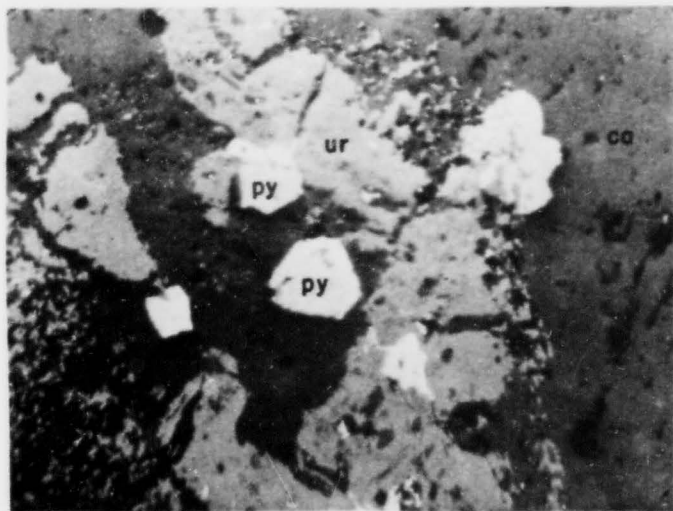


Fig. 43. Pyrite crystals and masses (py) which have veined and partly replaced uraninite (ur) in calcite (ca) matrix. Climax School Section mine. Polished section. X225.

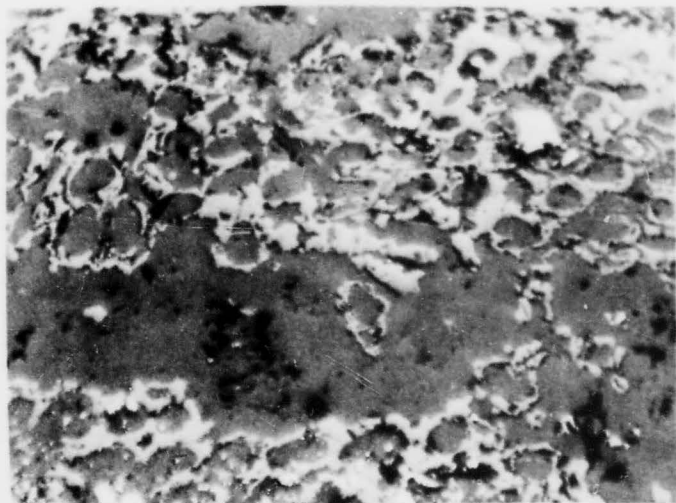


Fig. 44. Remnants of wood cell texture. Uraninite (light-gray), calcite (dark-gray) and pyrite (white). Black spots are pits in section. Climax School Section mine. Polished section. X135.

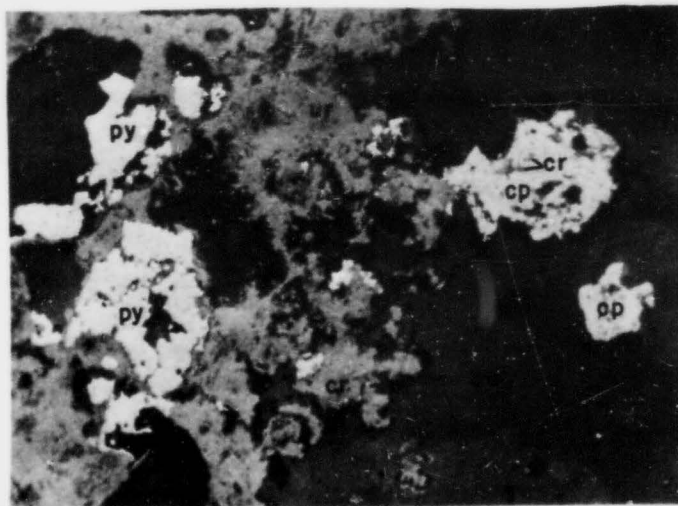


Fig. 45. Uraninite (ur), pyrite (py), covellite (cv) and calcite (ca) cementing sandstone. Chalcopyrite (cp) and covellite in calcite vein cutting sandstone. Pyrite has replaced part of a quartz grain (qt). Climax School Section mine. Polished section. X225.

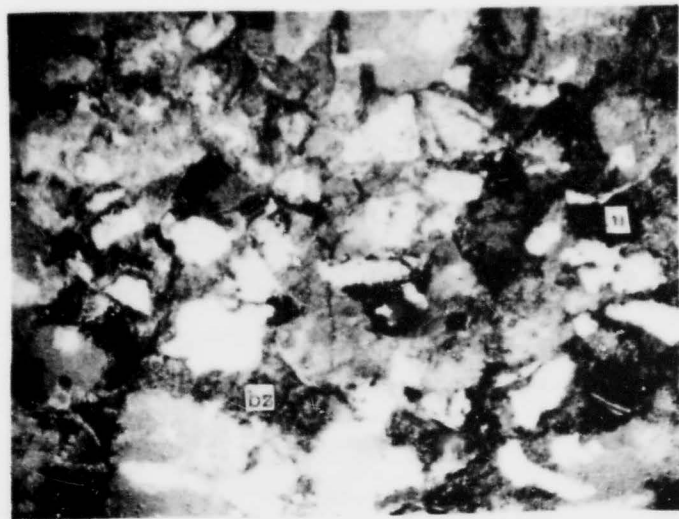


Fig. 46. Sandstone cemented by Beta-zippeite (bz) and uraninite (u). Climax School Section mine. Thin section. X107.

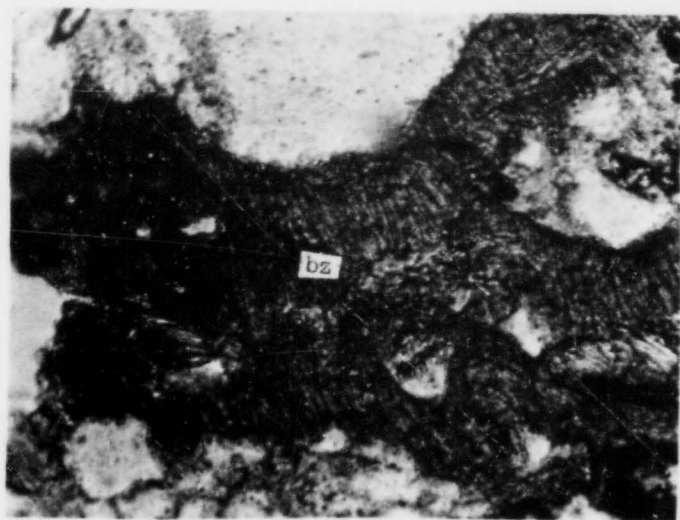


Fig. 47. Veinlet of Beta-zippeite (bz) in sandstone. Climax School Section mine. Thin section. X225.



Fig. 48. Boltwoodite needles in gypsum (gp) veinlet cutting sandstone cemented by Beta-zippeite (bz). Climax School Section mine. Thin section. X225.

# REFERENCES

- Abraham, H. (1945), Asphalts and allied substances: D. Van Nostrand and Co., Inc. Princeton, N. J.
- Baker, A. A. (1933), Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah, U. S. Geol. Survey Bull. 841.
- Barth, Tom, F. W. (1952), Theoretical petrology: John Wiley and Sons, Inc., N.Y.
- Emmons, W. H. (1949), Principles of economic geology: McGraw Hill Book Co., N. Y.
- Fron del, Clifford (1956), Mineral Composition of Gummite: Am. Mineral. 41, 539-568.
- Fron del, Clifford, and Ito, J. (1956), Boltwoodite, a new uranium silicate Science 124, 931.
- Fron del, Clifford, Riska, Daphne, and Fron del, Judith W. (1956), Powder data for uranium and thorium minerals: U. S. Geol. Survey Bull. 1036-G.
- Harker, Alfred (1939), Metamorphism: E. P. Dutton and Co., Inc., N. Y.
- Lindgren, Waldemar (1933), Mineral deposits: McGraw-Hill Book Co., N. Y.
- McRae, Otis (revised by Isachsen, Y. W.) (1958), Investigation of uranium veins in Cane Springs Canyon, San Juan County, Utah: U.S.A.E.C., RME-106.
- Palache, Charles; Berman, Harry; Fron del, Clifford (1951), The system of mineralogy; 7th Ed., Vol. II: John Wiley and Sons, Inc., N. Y.
- Ramberg, Hans (1952), The origin of metamorphic and metasomatic rocks: The University of Chicago Press, Chicago.
- Turner, Francis (1948), Mineralogical and structural evolution of the metamorphic rocks: Geol. Soc. Am. Memoir 30.
- Turner, Francis, and Verhoogen, Jean (1951), Igneous and metamorphic petrology: McGraw-Hill Book Co., N. Y.
- Van Krevelen, D. W., and Schuyer, J. (1957), Coal science, Elsevier Publ. Co., N. Y.
- Williams, Howell; Turner, Francis; and Gilbert, Charles (1954), Petrography: W. H. Freeman and Co., San Francisco.

